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TRANSACTIONS

OF THE

AMERICAN INSTITUTE

OF

ELECTRICAL ENGINEERS.

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TRANSACTIONS

OF THE

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

Vol. XV. JANUARY TO DECEMBER. 1898.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS.

NEW YORK, October 27th, 1897.

The 118th meeting of the AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS, was held at 12 West 31st Street, this date and was called to order by President Crocker at 8.20 P. M.

THE SECRETARY :—At the meeting of the Executive Committee this afternoon the following Associate Members were elected :

Name.	Address.	Endorsed by
BALSLEY, ABE	Chief Electrician, Terre Haute Electric Railway Co., No. 514 6½ Street, Terre Haute, Ind.	R. B. Harrison. Edw. G. Waters. Edw. P. Decker.
BALCOME, HERBERT A.	With The Eddy Elec. Mfg. Co., Windsor, Conn.	W. R. C. Corson. H. E. Heath. H. S. Rodgers.
CHILD, CHAS. T.	Editor, *The Electrical World*, 253 Broadway, New York.	J. Stanford Brown. Louis Bell. A. E. Kennelly.
GOLTZ, WILLIAM	Hathaway Building, Milwaukee, Wis.	F. B. Badt. Chas. D. Shain. B. J. Arnold.
JONES, M. E.	Contractor, and Student in Senior Class, Cornell University. Ithaca, N. Y.	Harris J. Ryan, S. B. Fortenbaugh. Fred'k Bedell.
LE CLEAR, GIFFORD,	Electrical and Mechanical Engineer. Partner Densmore & Le Clear, 7 Exchange Place Boston; residence, Cambridge, Mass.	C. A. Adams. E. H. Hall. H. B. Shaw.
THOMPSON, SILVANUS P.	Morland, Chislett Road, West Hampstead, London, N. W., England.	Chas. P. Steinmetz. Ernst J. Berg. Eskil Berg.

WILLIAMS, GEO. HENRY	District Supt. The Edison & Swan United Electric Co., Ltd., 134 Royal Avenue; residence, Culmore, Glenburn Park, Belfast, Ireland.	H. L. R. Emmet. A. G. Inrig. Ralph W. Pope.
WOTTON, JAMES A.	Electrician, Southern Bell Tel. & Tel. Co., P. O. Box 218, Atlanta, Ga.	F. A. Pickernell. A. N. Mansfield. D. I. Carson.

Total 9.

And the following Associate Members were transferred to full membership.

SAMPSON, F. D.	Manager, Charlotte Electric Light and Power Co., Charlotte, N. C.
DAVIDSON, A.	Cable Engineer and Electrician, Central and South American Telegraph Co., Lima, Peru.
DECKER, EDWARD P	Electrical Engineer, New York Telephone Co., 18 Cortlandt St., New York,

Total 3.

THE PRESIDENT:—As there is no formal business to attend to we will proceed immediately to the subject of the evening, and I take great pleasure in presenting Mr. Richard Lamb, who will read a paper on a novel and very interesting branch of electrical engineering, "The Development of Electric Cableways." Mr. Lamb will please present this paper, and as the paper is illustrated by lantern slides it will be necessary to darken the room, and Mr. Lamb will refer to them in the course of his paper.

A paper presented at the 118th Meeting of the American Institute of Electrical Engineers, New York, Oct. 27th, 1897. President Crocker in the Chair

THE DEVELOPMENT OF ELECTRIC CABLEWAYS.

BY RICHARD LAMB.

Large expenditures of thought and money have been made to devise means of transportation that can disregard the insurmountable difficulties of some surface roads, such as excessive grades, too much bridging, or too great a cost for roadway. The natural suggestion has been to make the roadway through the air, and air-ships, flying machines and suspended cableways have been sought for to solve the problem.

Macaulay wrote, "Of all inventions, the alphabet and printing press excepted, those inventions which abridge distance have done most for civilization."

The most baffling problems we have before us to-day are those of abridging distances. With all the expenditure of life and money that has been put into the endeavor, man has not as yet even been able to traverse this orb of the universe upon which we are living, and with untold riches as the goal, thousands stop within a few hundred miles of the Klondike, at the first short pass, to await a less hazardous season to risk the journey.

There are millions of feet of valuable timber in swamps standing within rifle-shot distance of convenient points of navigation that have been practically unobtainable. The miry soil makes regular roadbeds too expensive, and it has been as impossible to get the teams into the swamps as to get the logs out. It was to solve this particular problem of abridging distances that my electric cableway was built.

I first built a cableway, having portable iron bracket supports to attach to the trees, and an endless cable supported by sheaves upon the brackets. The cable was passed around a sheave which

was driven by a steam engine at one end of the line. This cableway worked well, and could haul logs for a distance of half a mile, which is farther than by any other method previously tried. I found that steam cableways are limited to straight lines, and as trees do not always grow in long straight lines, I devised a means by which the car would replace the traction-cable in its sheave if it was dislodged in passing a bracket on account of the cable line not being straight. But this did not obviate the difficulty of having to select the route with reference to a straight line.

FIG. 1. First Test of Logging Motor.

In the excellent article on "Railways in the Air," published in a recent number of *The Strand*, the writer states: "Two stout wire carrying ropes are laid parallel on standards of wood or iron and then stretched tightly *in a straight line.* (These words are in italics.) Aerial rope-ways cannot run around corners." This condition is due to the fact that a moving cable has a tendency to work itself out of its carrying sheave, unless the line of the pull of the cable is straight. This fact suggested to me the necessity of the traction cable being stationary. It was a natural advance in the line of thought to note that if a

sheave would transmit sufficient power to haul logs a distance of half a mile from the same, that it would be even more efficient if the power applied to the sheave was near by and accompanied the load on its travel. As an electrician, the cables of the steam rig naturally suggested to me conductors for an electric motor that would operate the sheave. Such a motor admits of the traction cable being stationary by passing it about the sheave several times and anchoring it at both ends; thus, the motor winds in and pays out the cable, on the principle of a capstan. The fact that the traction cable is stationary, and that the lower bracket catches the cable as the motor passes, makes a system of this kind the only one that can be operated upon concave and convex curved lines.

One of the essential features of the steam cableway is having the traction rope always parallel with the bearing cable. The disregard of the direction of forces in other cable systems has been one of the main causes of their failure. On approaching a support the cable naturally sags and the carriage has to be propelled up an incline. If the grade of the cable is steep, as it is in practice, and the power is applied in a horizontal direction, the resultant force will neutralize the pull, and the carriage will stop. Cableways, operated by horses upon the ground, pulling the carriage on the cable, have accordingly been inoperative. It was important, therefore, in the electric cableway, to have the traction cable always parallel with the bearing cable. Supposing the incline of the cable be raised until it is vertical, we would then have an elevator; the bearing cable being the guide and the traction rope the hauling rope, the motor being on the elevator car instead of at the top or bottom of the shaft. It is this feature that enables this system to operate on grades that would be impracticable by other methods.

This system consists of a carriage with grooved wheels in tandem that move upon a cable or suspended trackway. From this carriage is hung a frame, pivoted to the carriage so that it can maintain a vertical position regardless of the grade of the track. This frame holds an electric motor, preferably of an iron-clad cylindrical type. The motor is geared to an elliptically grooved sheave. A steel cable is wrapped around this sheave two or more times and is anchored at both ends. For the sake of economy in conductors, the upper or bearing cable is insulated from the lower or traction cable and is used to carry the electric

FIG. 2. "Pinow" Canal Motor.

current. The carriage is insulated from the suspended frame and motor. An insulated wire is attached to the carriage and conveys the current to the rheostat. The other pole of the rheostat is connected with a convenient part of the suspended frame. The rheostat is designed to control the speed and reverse the current. A circuit breaker is put in circuit. The current from the generator passes along the bearing cable to the carriage, thence through the insulated wire, through the rheostat, through the motor, to the frame of the motor, thence through the traction cable, back to the generator. At intervals along the line, connection is made between the traction cable and the ground. A bar of copper-coated iron is buried at the foot of a tree or post to which the cable brackets are attached. A well bonded copper wire extends from this ground plate to the lower bracket, upon which the traction cable rests. In swamp and canal service the plate is buried well into the moist earth. A most marked difference in the resistance is noted when the ground connections are disconnected. When connected, the resistance is the same as if the traction cable was the same size as the bearing cable.

In making the first saddles to support the cable they were designed for movable brackets, which can be easily put upon trees and removed to other trees when the line is changed to a different location. These saddles have a U-shaped clamp that goes over the cable and is bolted down with wedge-shaped bolts. Under the saddle is a petticoated recess, designed to shed rain-water from the insulation placed between the saddle and the bracket to keep the current from grounding or short-circuiting.

This develops a new feature in insulation. It appeared that many of the materials ordinarily serviceable for insulating were not available, owing to the fact that often a rolling load of 10,000 lbs. or more passes over the brackets, producing a grinding and crushing effect.

Lava, hard rubber, micanite, shellac, mica and its products, glass, porcelain, ozite and all products of rosin, proved to be too brittle. Vulcanized fibre was finally used and proved quite satisfactory for a time. As only 220 volts are used in logging plants, and as it is an advantage from a construction standpoint to have the insulation as thin as possible, sheets of fibre $\frac{1}{8}''$ thick were used. It was found that although this insulation was protected from the rain, by being shellaced and covered by a petticoat, after being exposed for some time, it would lose considerable of

its resistance, and while some of the brackets could be passed by the electric motor, the heavy load on others would cause a short circuit through the insulation. This was averted by painting the saddles, brackets and fibre with insulating paint, and by increasing the thickness of the insulation to $\frac{1}{4}''$ and using fibre that had been solidified under unusual pressure. This was found to work all right.

The saddles for the plant for the Erie Canal towing test, referred to hereafter, were made so that the tread of the bearing wheels would leave the rope, and the wheels would pass over the saddles on their rims, guided by flanges cast upon the saddles. On curves these flanges were made concave or convex as required. These saddles worked excellently; and the motor passed over them easily and satisfactorily. These brackets were insulated

FIG. 3. "Finow" Canal Motor on Cable Line.

with ozite and vulcanized fibre and painted with insulating paint.

Work in swamp logging demonstrated that small short saddles are all that are sadded, even for deflections in the line of from 20 to 25 degrees. The needle was much simplified by attaching to the brackets an insulated cone-shaped pin, over which the saddle is placed, by having a cone-shaped recess in the under part of the saddle to fit the pin. This recess also acts as a petticoat to protect the insulation. The question of insulating the cone-shaped pin was an important one. Vulcanized fibre could not be molded upon the pin. A material was needed that, while having a high resistance, would adhere to the pin, and that would stand a great crushing strain. It should be preferably non-hygroscopic, and show a minimum absorption of water.

Insulated trolley hangers were secured, that showed an insulation resistance measured under 150 lbs. vertical stress above 300,000 megohms, and after sprinkling with water one-half hour, measuring immediately above 300,000 megohms. After again sprinkling with water twenty minutes, they measured immediately above 300,000 megohms.

Tested for absorption after soaking in the water four days showed weight of 312.9 grammes; weight as received 312.7 grammes; absorbed 000.2 grammes. [Tests by Stone and Webster.]

In the insulated stud made for the saddles, the breaking strain measured over 35,000 lbs. At that point the insulation showed no signs of giving way, and the same stud was subsequently used for regular work. The instrument used for measuring the crushing strain measures only 50,000 lbs. It was thought best not to test above 35,000 lbs., which was more than needed in any service it would be required to perform. The pressure was put upon the top of the saddle and the bottom of the stud. As the thickness of the insulation is over twice as great on these saddle pins as was used on the trolley studs tested, the resistance should be at least over twice as great. [Test by Pope Mfg. Co.]

The best steel cables for cableways are the interlocked and patent locked wire rope. These are almost as compact as solid bars of steel, and yet can be easily coiled by hand in coils four feet in diameter. A simple coupling is used to connect the cables. The wheels of the car pass over these couplings so smoothly that the rider on the motor scarcely notices the fact. These points of connection are as strong as any section of the cable. An advantage in these interlocked cables is that they present a smooth surface of comparatively flat steel, which wears a great many times longer than the ordinary cables whose surfaces present round wires that wear through and unravel. These cables are made to bear much greater strains than the ordinary cables, and being so nearly solid they make much better electrical conductors.

The traction cable is made of $\frac{5}{8}''$ or $\frac{3}{4}''$ specially strong "19 wire" steel rope, with a soft iron wire core, in place of hemp, which is ordinarily used. This increases the conductivity. One of the most remarkable results in practice in this system is the fact that the traction cable does not have to be pulled very taut, in fact a sag in the cable seems to be of no disadvantage, as the motor does not tighten the line far ahead, even when doing con-

FIG. 4. Hauling Canal-boat at Trenton, N. J.

siderable service. The sag adds to the weight of the cable and to the friction on the brackets, and these two resistances act as an anchor for the traction cable, independent of the terminal anchorages. For example in the case of a trial plant for a German canal the resistance to be overcome by a motor, or its "draw-bar pull" was to be 645 lbs. Now at one pound per running foot of traction cable, the influence of the motor pull would only be felt 645 feet ahead of the motor. Therefore with motors distributed 645 feet apart, each one practically has its traction cable anchored from the motor ahead, and, in consequence the combined pull of all the motors is not exerted upon the terminal anchorage.

In the first plant, the clamps on each of the lower or traction cable brackets were made with steel jaws, with springs under them, such as are used on grip-pulleys. When the traction cable was pulled the clamps gripped the cable, and when the motor lifted the cable, on passing the bracket, the jaws released the cable. These clamps were found to be unnecessary.

In canal practice the terminals will be ten miles apart with tension stations every two miles. At the terminal stations rotary transformers will transform the high voltage alternating current to 500-volt direct current, and send the same each way a distance of five miles. Where the traffic justifies, a line will be placed on each side of the canal, when the insulated or bearing cables will be connected at intervals to feed each other. The anchorage of the traction cable will be made with a series of clamps, and the motors will be passed through them as canal boats through locks. At the end, the motor is released from its traction cable and is conveyed across the canal on a cable, or where masts are allowed on boats in the canal, by a hinged trussed track that can be opened like a gate, or raised out of the way. The handle of the rheostat is easily controlled from the boat by a cord attached to the handle. When the cord is pulled from the opposite direction to which the motor is to be run, the current is admitted in the proper direction, and the motor proceeds. When the cord is released, the handle flies back to a vertical or cut-off position, and the motor stops. When two boats pass they exchange motors by simply exchanging tow-lines and controller cords.

The first test of canal boat towing with this system was made on the Delaware and Raritan Canal at the Trenton Iron Works. The motor was made to go over concave and convex curves and up and down grades while towing the boat.

In reference to the test of canal boat towing on the Erie Canal, at Tonawanda, it is not necessary to make any apologies for the system. Superintendent of Public Works Aldridge, in his report to the Legislature, unqualifiedly endorsed the system and stated: "Early in the season of 1895 application was made to me to officially designate a part of the Erie Canal for the proposed test of the efficiency, economy and practicability of the so-called 'Lamb System' for improving the present system of towage on the canals of the State. The location selected was a piece of canal about one and one-quarter miles in length at Tonawanda, N. Y. The purpose was to select such a portion of canal as would embrace as many practical obstacles to the success of such a plan of towing as could be found anywhere in a section of canal that length."

In the report of Chas. R. Barnes, electrical expert for the Public Works Department of the State of New York, he sums up by saying: "The electric towing system appears to present

so many meritorious features that I have no hesitation in endorsing it as the system deserving preference over any other hitherto experimented upon, or likely to be devised in the near future."

So short a time was given in which to construct the trial plant that existing models had to be copied. The motor was over 9

Fig. 5. Test on Erie Canal at Tonawanda, N. Y.

feet in length; it weighed 2,213 pounds. The elliptically grooved sheave was driven by a worm-gear. The voltage, which was gotten from a trolley line, fluctuated from nothing to 500 volts, but seldom equalled the latter amount. The bridges under which the motor had to go were very low, and had to be ap-

proached by reverse curves on a grade of about 20 degrees. Trenches had to be dug next to the abutments to give room for the motor to pass under the bridges. Both convex and concave curves had to be passed over, and at one point the deflection was about 30 degrees. In spite of the difficulties the trial showed that the system performed economically and efficiently all that it was designed to accomplish.

In the plant recently constructed for trial on a German canal, the motor has been shortened to less than five feet in length; its weight reduced to 1,300 pounds. The worm-gear has been avoided by a double reduction direct gear, gaining 50% in efficiency over the worm-gear, and the elliptically grooved sheave

FIG. 6. Motor used at Tonawanda.

has been placed about the cylindrical electric motor, getting a large bearing surface and increasing the efficiency accordingly. At the test made at the Trenton Iron Works this motor, using a 5 horse-power Storey motor, wound for 500 volts, and going at the rate of 2.3 miles per hour, pulled 800 pounds when having the use of only 220 volts. This shows a remarkable efficiency, which is due to the mechanical principles utilized, viz., hauling the motor along by a fixed rope, attached to a capstan operated by practically a winch.

The uses to which this method of telpherage can be put are so numerous that I will not attempt to give descriptions of plans

that have been, and are now, being made for various parties, for such services as fortification work, rice culture, mining plants, ship building and sewer excavating plants. I will confine my descriptions to completed work.

Possibly the most universally serviceable application that has been made of the system is traversing motors with double hoisting drums for quarry purposes. These motors are to go on 700 feet span cableways. Each of these cableways has one end stationary and the other is movable on a curved track. It is designed to lift 10,500 pound rocks at the rate of 50 feet per minute and traverse at the rate of 300 feet per minute. At a test at Trenton made upon a temporarily erected cableway we raised 6,600 pounds, and ran on the cable at the rate of ten miles per hour, part of the time going up a grade of over 15 per cent. There will be no difficulty in these motors raising over 10,500 pounds and running 300 feet per minute. A 15 horse-power Storey motor is used. The rheostat reverses the motor and regulates the speed. A band brake also is used to regulate the stopping. This is controlled by a lever in front of the motorman. There is a safety brake to be used in case the band brake should fail. This is operated by a wheel. The shoe of this brake clamps the upper cable. It is attached to the car proper, and with the wheel handle oscillates with the carriage as it climbs or descends grades. A lever in front of the motorman is used to control the speed of the drums that raise and lower the skip. A friction clutch, controlled by a wheel handle, disconnects the traversing sheave gear and engages the hoisting drums or vice-versa.

In a place within reasonable distance of an electric plant having surplus power, these electric cable hoists can be erected and operated for a comparatively small cost. In contracting work, where electric lights are also used, these cable cranes can be used to great advantage. In other places the small generating plant necessary to operate these motors will add but little to the expense of an outfit.

Those who think that electrical machinery is of such a delicate nature that it is only serviceable for cities of advanced civilization, should go to the Dismal Swamp, and see a so-called dainty machine doing as rough and dirty work as any service to which a machine could be put. He would see the laborers, over their knees in mud, sawing down giant trees, and hear the woodsman

sing: "Stand from under, she's saying good-by to her neighbors." With a crash that throws mud and water high into the air a tree will fall and fill a space with broken limbs, embedding

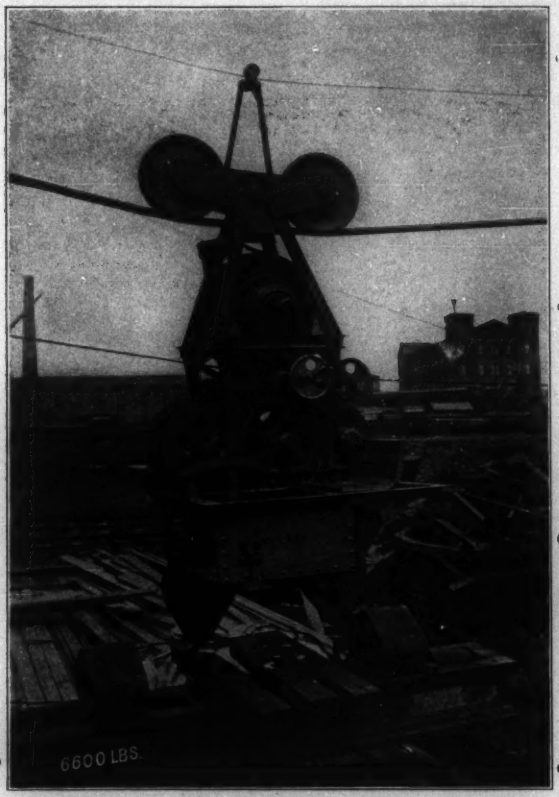

FIG. 7. Loaded Crane on Cable.

itself well into the mire. This means work for the motor. Logs are to be drawn from their beds, and when the ammeter in the generator room on the scow, for an instant runs up, possibly to

a point of overload, it is the motor overcoming the suction in drawing out a buried log. With the voltmeter standing at 220 volts, you would see the needle momentarily go to 35 amperes and then drop to about from 10 to 16, depending upon the size of the log. As the cone over the end of the log strikes a stump or a cypress knee, the needle flies to about 20 and then back, and as the log dives off from an obstruction it may be crossing, the cur-

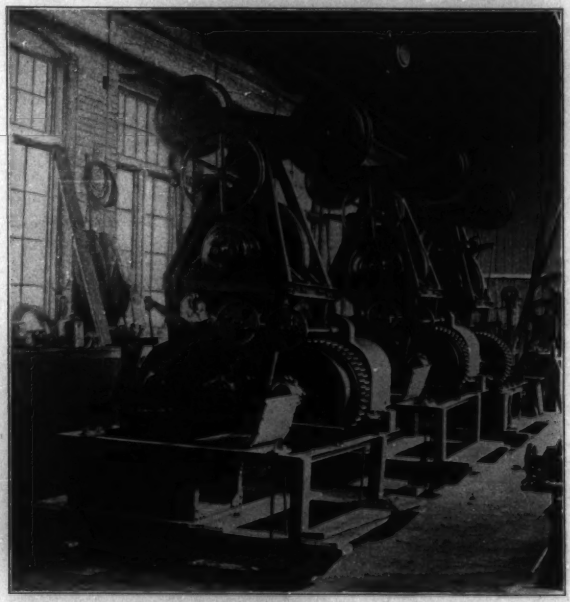

FIG. 8. Crane Motors in Shop.

rent drops to zero momentarily. Finally when the log reaches the tail-tree about 20 amperes is recorded as the log rises from the ground and hangs suspended by the hauling cable. This cable is reeved through a sheave, which is attached to the tail-tree fifty or more feet from the ground.

After a number of logs are drawn to the tail-tree, they are transported over the cableway to the terminal on the banks of

the canal. Reading the ammeter as the log comes in we see it start at about 5 then go up to 12 or 14, as it crosses the bracket

FIG. 9. Logging Motor working in Swamp.

saddles, then go down to 5 again. In this process of transportation, one end of the log is suspended by a car on the cable. The

end of the log is raised from the ground by holding fast the bight of the grip-block rope and going ahead with the motor. The block is attached to the car, when the same results are produced, as if the power was applied to the rope direct. When the end of the log has been raised to the proper elevation, the grip holds it from falling, and the rope is coiled and placed on the tongs which holds the log, and after getting a couple of cars loaded you are ready to carry your valuable logs from one of nature's worst fastnesses to a point where they become valuable to mankind.

The question has been asked, "do you require expert help about these logging plants?" In answer, I would say that I am satisfied with my superintendent. He has spent his life in swamp logging, and has had no chance for education, much less scientific studies. When I assembled the generator, the first time that I put up the plant, he put on a pair of rubber gloves, not wishing to run any chances of getting a shock, even if there was no fire in the boiler. While testing the plant a fuse blew out on the generator, and one of my negro help started on a run in the swamp and never returned again to work. I afterwards heard that he stated: "Mr. Lamb can't fool dis nigger, I done worked on the government dredge boat, and knows what a dynamite machine is."

In spite of the lack of electrical information of the logging crew, no inconvenience has been occasioned on that account. All features of insulation are provided for before the plants are shipped. An ordinary steam engineer acquires quickly the necessary information for running the dynamo. The motor is shipped with all parts adjusted, and the extent of the motorman's duties is simply to push the handle of the rheostat according to the direction he wishes to go.

The light first cost, the high efficiency, the ease with which it can be operated by ordinary mechanics, portend for this system an important place among the useful applications of electricity of this century.

DISCUSSION.

THE PRESIDENT:—This paper presents a very novel branch of our profession, one that few of us have paid much attention to, and it is interesting, I think, to note the fact that the simple methods of the trolley, that is the simple current-carrying wire from which the current returns by a ground or cable which is grounded, have replaced the earlier method of telpherage in which the sections were alternately positive and negative, and as Mr. Lamb pointed out, require the train of telpherage cars to bridge across from one to the other. That seems to be a radical improvement and enables a much simpler mechanical construction to operate successfully with the electrical conditions. In fact I should think that limitation of telpherage requiring a long train of telpherage cars to be operated in all cases was a very serious one as Mr. Lamb indicated, and would naturally prevent its general introduction. But the very simple methods employed by him which have been very clearly and completely set forth, I think will be appreciated. The subject is open for discussion.

MR. TOWNSEND WOLCOTT:—I would like to ask Mr. Lamb a question. I suppose that the insulation resistance of 300,000 megohms is meant for 300,000 ohms, isn't it?

MR. LAMB:—That is from the expert's report.

MR. WOLCOTT:—300,000 megohms?

MR. LAMB:—I recognize that a megohm is a million ohms. That is copied from his report.

MR. WOLCOTT:—It would be interesting to know how he makes it so many thousand megohms. May I ask what the efficiency of the worm gear was?

MR. LAMB:—I think we lost about 50 per cent. by the worm.

MR. WOLCOTT:—You think the worm gear lost about 50 per cent?

MR. LAMB:—Yes sir. We lost power not only from the fact that we used a worm gear but also from the fact that we had 100 per cent. more weight.

MR. WOLCOTT:—I mean what is the efficiency of the whole motor with the worm gear. You say the efficiency of the whole motor with the spur gear is 50 per cent. greater than the worm gear.

MR. LAMB:—We figured that we had an absolute loss of efficiency of about 50 per cent. on account of our worm gear. We doubled the capacity of our motors by changing to direct gear due to the fact that we get a very much better general arrangement with less friction on other parts, and also we get a very much lighter motor. We had however only 220 volts and the motor was wound for 500 volts, so we could not get an exact record for that particular motor.

THE PRESIDENT:—Do you reckon that, Mr. Lamb, the improved arrangement consumed very much less current?

MR. LAMB:—It consumed very much less current. Of course

the voltage in both cases was different, but taking the watts it shows a very much better efficiency.

THE PRESIDENT:—That is a perfectly good method of reckoning it, much better perhaps than some abstract mechanical test of the efficiency of gearing.

Are there any other remarks on this subject? It is certainly one which deserves discussion.

MR. CHARLES P. STEINMETZ:—There is one point I want to find out more about. It is stated here: "At the test made at the Trenton Iron Works this motor, using a 5 horse-power Storey motor, wound for 500 volts, and going at the rate of 2.3 miles per hour, pulled 800 pounds when having the use of only 220 volts. This shows a remarkable efficiency." I do not see that it shows any efficiency at all since no current is given. The current has to be known to get the efficiency, and since it is not given, the statement made in the paper, on the remarkable efficiency, is not proven.

MR. LAMB:—I could insert there the amperes. It amounted to 5 horse-power when you take into account 220 volts.

Mr. Steinmetz'e question can be answered in this way. That motor was wound for a 5 horse power and it pulled 800 pounds going at the rate of 2.3 miles an hour. No relative statement of efficiency was made, but it showed a most marked efficiency and gain over the other motor which never could have pulled 800 pounds at 2.3 miles an hour with the same amperes and voltages.

MR. STEINMETZ:—It merely shows that the second motor has a larger capacity, or larger power than the first, but gives nothing regarding the efficiency, as long as the actual amperes are not recorded.

THE PRESIDENT:—Have you any figures Mr. LAMB, in regard to the actual current input?

MR. LAMB:—I can give the amperes, but I have not them here.

THE PRESIDENT:—Mr. Steinmetz brings up the point that you cannot calculate back from the result you have got; that begs the question; that you have got to have the actual figures of input and output. You have the figures of output, but you must also have the figures of input in order to calculate the efficiency.

MR. JOSEPH SACHS:—I believe Mr. Lamb should give us the efficiency of the machine from the input at the motor to the actual pull and work done in moving along the cableway by that same motor. The spur gear and motor efficiency can easily be approximated. It would be interesting to hear something about the work-doing ability of his elliptically grooved cable-drawing sheave, which constitutes one of the basic elements of this system. I have been interested in this subject for some time and have heard a great many opinions pro and con regarding that sheave, and I would like to hear from Mr. Lamb personally regarding its efficiency and also the wear and tear upon the pulling cable. If we can approximate the losses in those two elements

we can get quite close to the total efficiency of the complete machine.

MR. LAMB:—Mr. Sachs' point is well put. The efficiency of the elliptically grooved sheave is a very important feature of this form of cableway. The electric motor, of which you have seen the picture, operating in the swamp, has been running for about a year and a half and I do not see any wear on that cable. If you had that same cable winding up on a drum, you would have a grinding effect and it would be increasing in size and lessening in size and winding over itself all the time, and there would be more wear upon it than if there is simply a couple of turns that play upon this elliptically grooved sheave which is guided and kept from riding, one cable on the other, by rollers. I do not see any reason why that cable should not last for four or five years at least, without any material wear at all. It is an inexpensive piece of mechanism anyway. In regard to the matter of the exact efficiency, which probably ought to have been spoken of first, I cannot give the facts, for the reason that we had, as I stated, a motor wound for 500 volts, and we only had 220 volts current.

MR. SACHS:—You got a certain amount af energy laid up by drawbar pull, feet per minute or feet per second, whichever way you might take it, or miles per hour, and what I am trying to get at, and what I think Mr. Steinmetz would like to get at, is simply the approximate energy from the input energy, and the actual work and output done by the machine. We have two sets of spur gearing there. We can approximate their efficiencies, and you have got the cable pulling sheave which we cannot approximate, because we do not know the exact facts, which you can probable give us. There must be more or less loss there, and probably a good deal, because your whole tractive effort must be gotten between that sheave and the cable. You must get slip there and you must get wear and tear on the wheel and on the cable both. I think if we can get those two points we can get very nearly at what we are driving at. The fact that the motor ran at 220 volts simply shows that it ran slower, and when it receives 500 it would run faster.

MR. LAMB:—Mr. Sachs can get the information he wants from the Superintendent of Public Works' expert electrician, Mr. Barnes's report on the Tonawanda test as to the first motor. We have not got the full data for the second.

MR. ELIAS E. RIES:—It seems to me that this whole discussion is greatly out of place. I do not think there is a gentleman present in this room to-night but who upon viewing the diagrams which we have seen upon the screen can see the whole operation very clearly and make due allowance for such losses as are likely to take place in such an installation. It seems to me we have a new proposition to deal with this evening, that is to say, a method of transportation or of conveyance by means of an overhead

motor carriage suspended from a cable. So far as the efficiency of motors is concerned, we all know pretty well what they are capable of. Whether this first motor has reached the stage which is within practical range to-day or not, is a question of very little importance. The only new features so far as losses are concerned which we have to contend with in this matter, it seems to me, are those involved in the frictional winding of the cable upon the drum and the constant ascending, you may say, of the carriage upon the cable, which has already been referred to, and the losses due to the particular kind of gearing which are necessarily introduced. All of these things, as has been stated by a previous speaker, can no doubt be eliminated more or less with further progress in this direction. The construction of the line, etc., will probably introduce some improvements later on, and so the questions of efficiency are very minor questions as compared with the new results produced.

It occurred to me, while Mr. Lamb was reading his paper, that if this system is as successful as his statements seem to indicate, that it might be extended to a great many other applications than that to which he already has applied it. For instance, some modification might be devised for the purpose of using such a system for ordinary conveying, excavating and such work as that, in which this motor, if you are going to use a motor suspended from the carrying cable to propel itself by a traction cable coiled around its own drum, may be provided with a supplemental drum operated by that same motor, while stationary, for the purpose of raising and lowering cars and boxes filled with excavated material, and then when they are raised the main propelling motor can be switched in and material so excavated can be carried off to a distance. That, for instance, is one application that suggested itself to me this evening while listening to Mr. Lamb's paper. And then it seems to me that it might be applied to a good many other purposes, for instance in agriculture. Of course those things would require more or less development; but the point I wish to make is that what the INSTITUTE ought to discuss, if they discuss the matter at all, should be with regard to the possibilities of this system of cableways which Mr. Lamb has explained, and not harp upon the merely minor points of efficiency or lack of efficiency, because those are well known things that we can deal with without that discussion.

MR. MAILLOUX:—I am not so much interested in the efficiency part of the problem as I am in the insulation part, and I would like to know something more about the fibre insulation which Mr. Lamb says he has used with success. Some ten years ago there was a system of electric railway signalling in operation on Staten Island, which system comprised a small dynamo on the locomotive, and required the rail to be cut into sections or blocks and insulated. I was called in consultation in connection with the matter with a view to overcome very many difficulties, (one

of which, by the way, was the capacity of the apparatus to do work under all conditions, such as the vibration of the car, etc.), although the principal difficulty was that of maintaining the insulation of the track and of keeping the sections electrically separate and distinct. I think that every material under the sun that seemed at all available was tried, and everyone of them failed. Fibre was the last resort and many experiments were made with all kinds of fibre, and used under all conditions, even made specially, but we could never depend upon it. The best results were obtained when the fibre was in the form of plates inserted between the fish-plates, with bushings. Very particular care was taken in designing the mechanical parts of the outfit so as to make it absolutely stiff and to avoid the slightest motion. But, as everyone familiar with railroading knows, it is impossible to make any sort of a mechanical joint in a rail as good as a rail that has no joints. That is the reason why welding has been introduced, so as to make continuous rails. In a short time, in fact, a very short time, the material would give out mechanically, become abraded and worn and would absorb moisture. The integrity of the fibre would be destroyed and it would no longer serve its purpose as an insulator. I very much fear that something like that is likely to occur with any known form of insulator subject to severe mechanical strains; and that is the reason why after having known of fibre being used without success in all forms and varities as it was known up to seven years ago, I would like to have some further information about the kind of fibre which is now being used with success.

As the difficulty referred to by another speaker of measuring 300,000 megohms, I may state for his information that it is not such a very difficult matter to measure 300,000 megohms. I had to do it in two places in Europe this summer and in both cases it was done without any difficulty and without any elaborate apparatus. In one case we had no difficulty in getting 3,750 megohms per volt with the ordinary double static Thomson galvanometer (of German make) and the scale used (with reflected light) set at about a metre and a half distance. In the other case we used the Rosenthal galvanometer with the scale about 3.5 metres distant and the readings made by a telescope. I find it can also be done even in my own office at the fourteenth story of a modern "iron-cage" office building, with an ordinary D'Arsonval galvanometer having a much lower figure of merit, (showing only about 1,000 megohms per volt). But in that case I use higher voltage. I use a small Crocker-Wheeler motor dynamo that can give me from 200 up to 600 volts, and it is only a question of "piling on the pressure" until you "get there." With a hundred volts it will measure 100,000 megohms, and with higher voltage we find no difficulty in getting up to 400,000 megohms. The outfit is used very often, for insulation measurements, especially for testing the insulation of high grade rubber

covered wires, and it has always worked with satisfaction, while it has the merit of enabling the measurements to be made with relatively short sample pieces such as would give no reading with lower pressures.

MR. JOSEPH SACHS:—The question of insulation, it appears to me is one that takes very much the same form as the question of efficiency; that if it does not work now it can be made to work later on. I think that if Mr. Lamb has not got the proper kind of insulation now, a little further experimenting will produce it. Now the question of efficiency is another one. Quite true, it cuts no figure in the present development. When you haul logs, as Mr. Lamb says, you have no competitor. A system of this or similar nature opens up previously inaccessible regions where other methods would fail entirely. Much of this success depends on the fact that weight is not used for tractive effects. The canal boat hauling problem is, however, one in which there are many competitors and not by any means the least is the humble mule. Then we have steam canal boats, and various methods of electrical boat propulsion on canals such as the Erie, which forms only a part of the complete route. These and other considerations are of the utmost importance. There are at least a score of electrical and mechanical methods for this purpose. Efficiency is a very important factor in all when they are being exploited to compete with other methods. Aside from efficiency Mr. Lamb might tell us why his system is superior to other similar hauling systems several of which will suggest themselves. It may be interesting to note another point which is interesting and perhaps quite as important as efficiencies or insulations; that is the regulation and control of the motor. When a motor of the type here described is used for log-hauling it is essential that the operator should be right at the motor and is therefore seated on the carriage as it would be inadvisable to place him elsewhere. In this position he has all switches right at hand. Boat hauling, however, brings in another consideration. Unquestionably the hauling method is the superior method of boat operation in narrow water ways and far surpasses any propeller method. Mr. Lamb will probably remember a little discussion that we had some years ago regarding whether the motor ought to be regulated by a man upon the carriage itself or whether that motor ought to be regulated from the boat. I am glad to see that Mr. Lamb has come around to my way of thinking although he has not adopted my method. Our co-member, Mr. Martin, and myself, some years ago spent some time in writing "Electrical Boats and Navigation." We succeeded in making some prophecies and one of them was that the most feasible method of operating canal boats was to haul them and to regulate from the boat. Now the method adopted by Mr. Lamb comes to that point It does away with the man upon the motor itself and probably saves his pay, which in the long run amounts to something as the hauling of a

boat through the Erie Canal takes several days. The method he describes, however, while far superior to the man being placed upon the motor, has objections, and one of them, which I would like to ask him about, is what happens when the motor slows in speed? The hauling rope undoubtedly slacks up, and certainly the regulating rope is similarly affected. There are various other times when similar conditions occur, and the boat will probably stop owing to the cessation of current in the motor. A method which seems to be more correct and devoid of the objections to the other has the regulator and switch upon the boat itself. Systems of electrically hauling canal boats, wagons and logs have been experimented with for probably the past fifteen years. Messrs. Ayrton and Perry were amongst the pioneers in this direction. Aside from boat and log haulage other applications were suggested. In one of these such hauling motors running up in a small suspended track or wireway, are connected by ropes or chains to wagons on the common roads. A recent installation now being experimented with contemplates the operation of electric motor wagons on common roads, current being supplied by an adjacent conductor. A hauling motor method, however, has advantages as any wagon may be hauled. The utilization of such carrying methods in quarries I believe is now being attempted by Mr. Lamb, and in conjunction with the motor carriage a hoist is used.

MR. JOSEPH BIJUR:—Recently I visited a country where considerable lumbering is being done, and I noticed that the lumbering is largely confined to the water-ways, and that they bring some of the more distant logs to the water by skidding them over frozen brooks and slides in the winter.

It would seem that any method by which logs could be brought to water-ways would be very valuable, but there appears to be this objection to the system which Mr. Lamb has just explained, namely, that perhaps the railway has not sufficient capacity for carrying logs to convenient water-ways to make it worth while erecting the lines. That is, as to the railway shown on the screen to-night, the car would take one or more logs from wherever the lumber was cut to the end of the line and then perhaps come back and again carry a limited number of logs to the end of the line.

If that were the case I should think that the capacity of the line would be small, unless it was so arranged that a number of cars should follow each other successively around in a circle. I should like to hear from Mr. Lamb whether there is any method for overcoming that apparent objection.

MR. LAMB:—The number of logs hauled per day is only limited by the amount of capital put into the plant. If you build a large enough generator and put your cableway on both sides of the tree, your empties go out and your loaded come in and you can bring in as many logs as you wish. But I do not want to

have it understood that I have ever anticipated that this system for logging would supplant the regular logging railroads where you have to go a very long distance. The number of logs that you would haul by such a system would make the system inefficient. It is only for short distances. We do not recommend it for over two miles. But the fact of the case is that I have tried every form of logging, to load the logs after felling them and putting them on the cars in order to carry them to the mills, and there is not a system in existence to-day that in actual practice logs over an average distance of 500 feet, with the exception of the "pull boat" system, which is simply a large double drum engine that winds in and pays out a cable reeved about a large sheave anchored into the swamp. Tongs are attached to the cable, which engage logs, which are hauled in over the ground, tearing everything before them, including sometimes the cable itself. This system is not efficient. They do not haul in very many logs per day. What we are after is to get a system that will go beyond 1200 feet into these swamps that are miles deep. We get out logs near Norfolk that have been standing there for centuries that bring $20 a thousand feet at Norfolk City. They could not be profitably logged heretofore. But to go into the regions that my friend refers to and compete with streams and skidding by sleds was never anticipated. We can haul a large number of logs from a reasonable distance by having a large enough plant and enough motors.

MR. STEINMETZ:—Mr. Lamb has given us a very interesting method of canal boat propulsion. But I would like to ask one question. Why do we need two heavy cables? Why couldn't we put the ordinary trolley line over the canal and the ordinary propellers on the boat? We know all about the propeller and its action and that it will propel the boat, and that the motor will run the propeller. Why have these heavy cables instead of the ordinary trolley?

MR. LAMB:—I would refer Mr. Steinmetz to Mr. Sachs' and Mr. Martin's work on the subject, which is excellent and exhaustive, and proves that the trolley propeller is a very inefficient way of doing the business.

MR. T. C. MARTIN:—There is another point besides efficiency. As I understand it the objection of putting a motor directly on the dishpan propeller is that the banks of the canal would not stand the wash, and for that reason the application in that form would be very quickly forbidden. The question of efficiency would cut no figure there at all.

MR. SACHS:—Even though the Legislature—the present one is particularly good or likes to appear so—would appropriate enough money to bank up and wall up the canal and fix it so that the wash would not do any injury to the present mud bank, the efficiency differences are so enormous that by all means we want to adopt something to pull the boat instead of pushing it

from behind. I think the propulsion of boats in narrow waterways is one that has been gone into quite exhaustively and found to be a problem a little different from the propulsion of a boat in an open water, and that problem increases very severely when you go to push that boat with a screw. I think Mr. Steinmetz himself will appreciate that fact. When you take a hauling motor of high efficiency, probably as Mr. Lamb will get his machine down to a single reduction, as he probably hopes to get his hauling sheave down to an efficiency of probably 90 per cent. —with a motor of that kind, and if not that motor some other form of hauling motor, I think you can probably get twice the efficiency, if not more, than you can with a single screw propulsion for the same number of boats, the same speed and the same weight carried by each boat. I attempted to show that some time ago, and succeeded perhaps poorly.

MR. H. WARD LEONARD:—I also am quite interested in this question of the insulation, but from a different standpoint, as I have been doing some experimenting in that line with an insulating material, which it seems to me might have answered for this purpose. I have recently been making insulating joints in which the two parts of the insulating joints are held together with enamel, and it seems to me that it has the features which are described in this paper as necessary, as being non-absorbent of moisture and of high insulation, and having sufficient strength to stand the strains that were brought upon it mechanically.

MR. MAILLOUX:—I would like to ask Mr. Leonard if that material has elasticity. I think that is the principal physical qualification. It must have in addition to insulation a certain amount of elasticity.

MR. LEONARD:—I subjected the insulating joints I speak of to very severe rapping with a hammer, while they were holding the weights I thought they would meet in practice, and also subjected them to all the strain we could put upon them by means of a wrench. Of course it must be borne in mind that there is a very marked difference between enamel for such use and anything in the shape of moulded glass. The strain which enamel will stand is enormously greater than what the mere moulded glass will stand, and most insulators that have been tried and found wanting, in the way of vitrous material, have been in a moulded form, and they have not the same strength.

MR. E. E. RIES:—I wish to say, since the discussion has drifted again to the question of insulation, that a number of years ago I had occasion to insulate the connecting rods of a very powerful steam locomotive, and after going all through this question in my endeavors to find an insulating material that would stand the strain of such heavy work, I met with exactly the same difficulties as have been recited here this evening. I finally adopted a new method of insulating, in which I used ordinary vulcanized fibre. I took a sheet of hard fibre about three-

sixteenths of an inch thick, bent it around into the form of a circle, and by means of hydraulic pressure forced the sheet of insulation between the brass bushing or collar which fitted over the driving crank of the locomotive wheel, and the opening or hole in the end of the connecting rod. The bushing, which had been made somewhat longer than usual and prepared with a conical or tapered end, was first turned down a trifle to reduce the outside diameter. The insulation was placed within the hole of the connecting rod and the brass bushing was then forced into place so as to leave a rigid wall of insulation between it and the rod, after which the projecting tapered end of the bushing was turned off so as to leave the bushing of the proper length. That insulation was by this process driven in so hard, under such enormous pressure, that it withstood the severe mechanical strain to which it was subjected perfectly, running day in and day out, and outlasted the ordinary brass bushings which are usually placed in those connecting rod ends. The insulation was also tested electrically at the frequent intervals by means of an ordinary galvanometer and found quite satisfactory, scarcely any deflection of the needle being noticeable. An incidental advantage of this construction was that the side rods of the locomotive ran much easier and were free from the mechanical vibration or "ring" which formerly characterized them when in operation.

Now, it occured to me that instead of attempting to patch up an insulating arm such as Mr. Lamb is using to support his traction cable by inserting a flat strip of insulation between the metal of the arm and a top plate which must necessarily be riveted or dovetailed or held on in some such way as that,—that if Mr. Lamb will follow the principle which I have adopted, and make his rest for the lower cable in the form of a sleeve, through which can be passed either a bolt capable of being screwed into the bracket, or the cylindrical end of the bracket itself, this bolt or bracket-end being forced into the sleeve containing the insulating sheet by hydraulic pressure, that he will get such a firm job that it cannot possibly be displaced, no matter what weight might be placed upon it. The traction cable would rest upon the upper surface of this insulated sleeve, which could be in the shape of a supporting saddle, and this sleeve or saddle, if necessary, could be connected directly with the feeder wires or with whatever circuit connections might be required to complete the installation.

MR. LAMB:—The trouble in that case would be, that, placed on the side of the saddle that the cable rests upon, it cannot be in any way covered and it would be exposed to water. The method that we are using is the simplest thing that could be devised. This cone-shaped pin (illustrating) is covered with half an inch of insulation, and this insulating material is pressed upon the pin at a pressure of 100,000 pounds to the square inch; it becomes

almost like a solid piece of iron. Over the top of the pin the steel saddle fits. The cable rests on the top.

MR. RIES:—That is exactly what I referred to—a plan of that sort. It is immaterial whether you have it in the shape of an umbrella head—

MR. LAMB:—It has to be moulded, though. We cannot mould fibre. This fibre cannot be moulded; it has to be rolled.

MR. RIES:—Of course such a substance would be preferable but at that time there was no such substance obtainable. Yet I obtained very excellent results. I was under the impression that Mr. Lamb had not yet found a material that he could mould to the shape he desired and which at the same time would be sufficiently strong to answer the purpose.

THE PRESIDENT:—As I understand, this method of insulation you employ is entirely successful?

MR. LAMB:—Entirely so.

THE PRESIDENT:—I think this discussion is entirely out of place. Mr. Lamb has already a successful insulation. Several members of the INSTITUTE have been instructing him in connection with a matter he has already solved and apparently better than they have.

MR. LAMB:—This insulation is non-hydrostatic. You can throw water on it and no two drops will stand together. They will all separate in small particles over the whole piece. It stood with a half inch thickness on one of those pins, a pressure on the top and a pressure on the bottom of 35,000 pounds without showing any indication whatever that it had had any pressure upon it, or any abrasion. We rolled heavy weights over it and it was in no way affected. I would not care to vouch for this statement, but a gentleman told me that a lot of this insulating material was put around a pebble and was thrown from one of the high buildings down at the end of Broadway, and it broke in two, the pebble and the material, just as though it were one kind of material.

MR. A. E. KENNELLY:—I would like to ask Mr. Lamb what is necessary to be done in the case of a break down, if you want to put the motor on or take the motor off at some point on the line. It is necessary to start at the beginning of the line, or can you take up 14 feet slack at any point, or can you put 14 feet in the traction line at will?

MR. LAMB:—You cannot take it off on the line. You have to pull the motor to the terminal to get it off. The terminal stations are situated at intervals along the line. At these places you can take the motor off. You can pull the motor along without unwinding the cable from the sheave or taking it off the cable.

MR. MAILLOUX:—Does the motor ever run off the track?

MR. LAMB:—If it could, I would have dropped with it before this. It is far more stable than a surface track would be, as the center of gravity of the motor is below the bearing rail, and deep flanges are on both sides of the wheels.

MR. SACHS:—Mr. President, I do not think Mr. Lamb's motor ever takes any notion to run off the track, and I think that is rather one of the features that militates against it from the simple fact that it is mighty difficult to take it off the track. In taking off a motor from the track, in case it should be absolutely essential to do so, say for instance through accident at some intermediate points between teminals, it would be necessary to take off the pulling sheave. That pulling sheave encircles the elliptically grooved wheel say two or three times. That means so much slack cable. There must be some point where you will probably get enough slack cable to make it necessary to stop taking the motors off the line. But I should not think it would be essential at all to take any motors off the line on a system of that kind, for the simple reason that if a motor should break down, the motor going in the opposite direction would push that broken down motor back to the point it came from and the next motor coming along would pull the waiting boat ahead. So I think there is no difficulty there.

MR. PAUL G. BURTON:—I would like to ask Mr. Lamb a question about the wear of this cable in the sheaves. The method, as I understand it, is simply to make two or three bights right around the sheave in much the same manner they are using throughout the city in these hoisting engines—what is commonly called a "niggerhead" in the trade. As far as I can discover, and I have had a little oversight of machinery—there is a good deal of wear even where there is simply a rolling friction. In this the cable enters on one side of an elliptical surface and goes out on the other. Consequently there must be a grinding all the time, and I would like to know what effect that has in the way of wear on the sleeve and on the cable. It seems to me it must be much more considerable than he claims.

MR. LAMB:—That depends on the difference in hardness which you would have between the cable and the face of this elliptically grooved sheave. You do not of course intend to build a sheave as hard as you would have the cable and expect the cable to last longer, because the face of this sheave is made so that you can remove the part that wears very easily and put another one on. It is inexpensive. But they have a very fair life and they are much larger than the winch-head that you referred to, and the bight of the rope is different. In one case you have a large circumference; in the other you have only 12 inches diameter. It in consequence would wear much harder. The actual distance of play is not very much and the groove is very slight because it is paying in all the time just about evenly except when it is going around a curve. The two rollers in front and in the back guide the rope and keep it in the right place on the sheave. On the other hand, when you have got a drum that is winding up a rope and it is elliptical in its groove, it pays off and winds

down the cable a long distance on the drum. We only have in one case two coils of rope on, (three coils at the most), and they are guided, and there is very little play upon the sheaves.

MR. SACHS:—I would like to have Mr. Lamb answer this question that I asked some time ago—that is, whether it is not a fact that one of the difficulties with this rope hauling method is that the motor acts in a very fantastic and cranky fashion; that it takes sudden notions to stop and sudden notions to go ahead, and all that sort of thing. The motor may slacken its speed and the boat may be retarded slightly. That may mean an increase of speed or it may mean a stopping of the motor. In either case it must mean the attention of the attendant on the boat at once. I would like to know if there is not some system that Mr. Lamb has devised to obviate these objections, and if they are not real.

MR. LAMB:—There would not be any reason for a motor stopping or not stopping except the loss of voltage. In the case of logging I never knew that to happen. On some of the Erie traction experimental trips it did happen. Our line was connected with a street trolley line and our voltage went from nothing to 500 volts. Sometimes the motor would stop, sometimes go slow, sometimes go fast. But there is nothing in the design of the motor that would give grounds for thinking it would go faster than at other times.

MR. SACHS:—It was not a question of design of motor. It was a question of whether the regulating rope, the rope that you have connected from the operating controller and switch, unless you employ the rheostat for both functions, does not slacken as it certainly would. For instance, we will consider the boat and the motor propeller being propelled at a certain rate, and that suddenly you meet a curve in the line, or something of that sort, and a heavy load is put on the motor in addition to what is already carried. That would mean a slow-down, especially where you have not particularly excellent distribution. That slowing down must certainly mean that your rope is going to slack and it certainly needs but very little slack in the rope to bring the rheostat back to the stop position;—at least so I should presume.

MR. LAMB:—What would make the motor stop would it not be the pull of the boat, the extra heavy pull?

MR. SACHS:—I know—but your boat is moving forward. Its momentum is carrying it ahead at about the same speed as the motor previously pulled it. Now the motor gradually slacks up—it meets a curve—it has got to go up a steep incline, or there is some difficulty in the propelling machinery, and it slows down. That means that the boat is carried ahead and will be carried ahead for a few moments. But the motor is gradually slowing; that means that the rheostat is going back to where it started, and it means that the man has got to come forward and pull it.

MR. LAMB:—That would not be the condition in practice. There is nothing on the line of the cableway that would stop

that motor from its speed except the pull, and when the pull ceases then you want your motor to stop and that is the only time that the controlling rope is slack.

MR. SACHS:—If you are going to build a motor to overcome any possible obstruction and any possible curve at the maximum load that the motor is going to pull, you are going to have a pretty big motor. The question of weight has to be considered in the construction af carriages.

THE PRESIDENT:—I think it is rather late to take up that question of the relative efficiency of hauling and propulsion.

[Adjourned].

A paper presented at the 120th Meeting of the American Institute of Electrical Engineers, New York, Dec. 15th, 1897, Vice-President Steinmetz in the Chair.

SPARKING, ITS CAUSE AND EFFECTS.

BY THORBURN REID.

Present theories in regard to the operation of commutation and the nature of sparking, show considerable progress beyond those of a few years ago. The most important step forward was taken when the reactance of the coil under commutation was recognized as the greatest obstacle to perfect commutation, and the duty of overcoming this reactance was assigned to the E. M. F. set up by the cutting of the lines from the field by the coil under commutation. It was also recognized that this must be limited by the available reversal E. M. F.

This was a long step forward, but it stopped just short of a complete explanation of the phenomena involved. This failure was due to an erroneous idea, which has fastened itself on the theory from the start, that injurious sparking was due to the current sparking across the gap between the brush and the receding segment, by reason either of incomplete reversal of the current, or of over-reversal.

I shall attempt to show in what follows, that sparking from either of these causes may be harmless, and that the real injury is done before the segment leaves the brush.

Taking first the simplest case of commutation, that of a coil of n turns with its ends connected to adjacent commutator segments, we may state the operation of perfect commutation thus:

First, consider a coil which is approaching a brush through which the current is entering the armature from the outside circuit. The brush covers the segment connected to one end of this coil, and half of the brush current is passing through the

coil from segment 3 to segment 2 (Fig. 1), the other half from segment 3 to segment 4.

Second, consider this coil receding from the brush, which now covers segment 2, as shown in Fig. 5. Half of the brush current is now passing through the coil from segment 2 to segment 1, the other half passing through the next adjacent coil from segment 2 to segment 3. The current in the coil 3–2 now has the same value under the conditions shown in Fig. 5, as it had before in Fig. 1, but its direction of flow through the coil has been reversed. Between these two positions of the coil with reference to the brush, the whole operation of commutation has taken place, requiring generally but a very small fraction of a second.

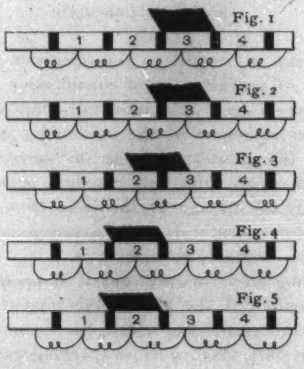

Fig. 2 shows the first operation in commutation. The two ends of the coil are now connected through the brush, and the current passing around the left hand circuit of the armature has two possible paths, the one through segment 2, the other through segment 3. The amount of current which will flow from the brush direct to segment 2 depends on the difference of potential between the brush and segment 2, and on the resistance of contact area of segment 2.

Since the difference of potential of any two points in a circuit is the same through whatever path the current flows, this D. P. is equal to the algebraic sum of the potentials reckoned from the point of contact of the brush with segment 2 to the point of contact of the brush with segment 3, across this contact

and through the coil to segment 2. The D. P. in the commutator segment need not be considered, as it is neglible. The D. P. in the brush itself is also negligible.

The D. P. across the area of contact of segment 3 varies directly with the current flowing across it, and inversely with the area of contact. The D. P. in the coil 3–2 depends on three factors, the CR drop in the coil, the counter E. M. F. of self-induction due to change in the value of the current, and the E. M. F. due to cutting the lines of force of the field. This last we will call "reversal E."

The CR drop varies with the current flowing in the coil. The counter E. M. F. or inductance drop varies with the rate of change of the current in the coil. Reversal E varies with the rate of cutting of the field lines.

The CR drop at the contact area and the CR drop in the coil both oppose the current, and the inductance drop aids it as long as the current is decreasing. The reversal E may act in either direction, but is usually opposed to the inductance E. Therefore the D. P. between the brush and segment 2 equals the CR between the brush and segment 3 plus the CR in the coil 3–2 minus the inductance drop in the coil, plus reversal E. It is seen that, as the brush moves over from the position of Fig. 2 to that of Fig. 3, the area of contact of segment 2 increases, while that of segment 3 decreases. Thus the resistance of the current path from the brush to segment 3 and through the coil to segment 2 is continually increasing, while the resistance from the brush to segment 2 direct is decreasing. Therefore the CR drop across the contact area of segment 3 will increase or decrease according as the contact area or current decreases more rapidly.

Thus throughout the period of commutation there is an increasing opposition to the passage of the current through the segment 3, and an increasing facility for its passage through segment 2 due merely to the changes of the areas of contact of the brush with the two segments, and to the consequent changes of resistance.

For perfect commutation which is the case we are considering at present, the impedance of the coil E should always be equal and opposite to the reversal E as will appear later.

The next period in commutation is that during which the current in the coil is increasing to its final value after having passed through zero.

When the current in the coil is zero, one-half of the brush current is passing through each of the two segments under the brush on the proper assumption that the current divides equally between the two halves of the armature. The CR drop at the contact surfaces of the two segments will then be inversely proportional to the area of the contact surfaces, and the difference between the impedance E and the reversal E will then, as before, be equal and opposite to the difference between the two CR drops at the contact surfaces. It should be noted here, that, although the current in the coil is zero, its rate of change may be considerable, and thus cause considerable inductance E.

While the current in the coil is increasing, the inductance E is in opposition to the current, while the reversal E is in the same direction with the current. Thus while in the first period of commutation, the inductance E prevented the decrease of the current, in this period it prevents its increase. The reversal E on the other hand aids the decrease of the current in the first period, as well as its increase in the second. The increase of the contact surface of segment two, and the decrease of that of segment 3 still continue to aid the flow of the current from segment 2 through the coil to segment 3, so that the effect of all these varying E. M. F.'s is just the same throughout this period as throughout the first period, but the resistance of the coil itself, which in the first period aided the decrease of the current, in this period opposes its increase.

Finally, just as segment 3 leaves the brush (Figure 4) the current in the coil becomes equal to one-half the brush current and no current passes through from the brush to segment 3, and the segment leaves the brush without any difference of potential between it and the brush.

Now consider how the current should vary during the period of commutation, so that the energy of commutation will be developed equally over every part of the contact surface, and so that the amount of energy developed shall be a minimum.

First consider the variation of the current which will satisfy the first of these conditions. This condition will be fulfilled if the current density in every section remains constant as long as the area of contact is changing; for every part of the segment remains in contact with the brush for the same length of time, that is, the time required for that part to pass from the heel to the toe of the brush. Therefore, since every part is receiving

energy at the same rate and for the same length of time, the energy developed in each part is equal. While the whole segment is covered, any change in the current density will affect every section equally, so that the current may vary in any way during that period, without causing unequal distribution of energy.

Consider how the current should change so as to develop the least energy. That is, how the current must be distributed between the contact surfaces of the segments so as to develop the least possible amount of energy.

Let R_1 and R_2 be the resistance of the two segments, and C_1 and C_2 the corresponding currents, C being the total current flowing. Then we have for the rate at which energy is being developed at any period.

$$W = C_1^2 . R_1 + (C - C_1)^2 R_2 \qquad (1)$$

Differentiating and equating to zero, we have

$$C_1 = \frac{R_2}{R_1 + R_2} C \qquad (2)$$

To determine whether this gives a maximum or minimum value, substitute in equation (1) for C_1 the values $C = 0$ and $C_1 = C$ and we get for $C_1 = 0$, $W = C^2 R_2$ and for $C_1 = C$, $W = C^2 R$. Both these values are higher than that obtained by substituting from equation (2) in equation (1), namely:

$$W = \frac{R_1 R_2}{R_1 + R_2} C^2$$

Therefore that value of C_1 makes W a minimum.

This means that for each position of the brush, the energy developed at the contact surface will be a minimum when the current divides between the segments under the brush in the ratio of their areas of contact. It is seen that under these conditions, the current density remains constant, and that therefore the requirements of equal distribution of energy are also fulfilled.

Perfect commutation may now be defined as a complete reversal of the current in the coil under commutation in such a manner that the portions of the current flowing through the two segments to which the ends of the coil are connected, shall be proportional to the respective contact areas of the segments.

It was shown above that $C_1 R_2 = C_1 R_1 + CR$ drop in the coil

plus the inductance E in the coil plus the reversal E. If therefore the sum of the CR drop of the coil plus its inductance E were always equal and opposite to the reversal E, C_1R_1 would be equal to C_2R_2, which is the condition for perfect commutation as defined above.

Following are some of the various ways in which imperfect commutation may occur, and the manner in which this imperfect commutation causes injury to the commutator.

First. Suppose that the current flowing across the contact surface of the receding segment does not decrease as rapidly as the contact surface of that segment decreases. The current density then increases and is a maximum at the last part of the segment that touches the brush. More energy is thus concentrated at that point than at any other, and owing to the fact that time is required to conduct that energy to other parts of the segment, that part will be raised to the highest temperature. This temperature may be high enough to melt, or even volatilize the copper of the segment, therefore when the brush leaves the segment, the current continues to flow through the film of melted copper, volatilizes it and draws an arc. This arc constitutes the injurious or "vicious" spark. The removal of the volatilized copper from the receding edge gradually wears that edge away. Reduction of the contact surface thus continually increases the current density, and the arc is formed at an earlier stage of the commutation when the current to be broken is greater, and thus the spark increases in viciousness until the commutator has to be turned down before the machine will run at all.

Again the energy developed at the receding edge of the segment may not be sufficient to melt the copper. In this case the current to be broken when the segment leaves the brush will jump across from the brush to the segment. This spark has no deleterious effect, since most of its energy is developed in the space between the segment and the receding brush, instead of being concentrated at the edge of the receding segment. This spark is of the same bluish color as that of the Ruhmkorff coil, by which it may be distinguished from the injurious spark, which is yellow.

Second. Suppose that the current flowing across the contact area of the entering segment increases more rapidly than the contact surface increases. The current density in that part of the segment then increases, and more energy is concentrated at

this point than at other parts of the segment and it will accordingly be raised to a higher temperature. If this temperature is not high enough to melt the copper, no harm results and there is no spark, since the contact is not broken at that point. If, however, the temperature produced is high enough to melt the copper, the melted copper may be carried along by the brush, and the entering edge of the segment is thus gradually eaten away. This will not show by any sparking immediately, but it will eventually cause a spark to appear in the following manner: The eating away of the entering edge of the segment gradually reduces the area of the entering segment and thus increases the resistance of that segment. This delays the decrease of current in the receding segment, and the current density in both segments increases until the temperature gets high enough to produce a spark as described in the first case of imperfect commutation. Another incidental injury that may occur is the deposition of the melted copper at the back of the segment, thus raising the surface of the segment at that point, and this, together with the depression of the surface at the front of the segment, would cause the brush to jump and chatter, which of itself would cause deleterious sparking.

This would explain the cases where a machine runs perfectly sparkless when first set up, but after a time commences to spark, the spark increasing in intensity and deleterious effect and disappearing when the commutator surface has been turned up, only to reappear after sufficient time has elapsed. The wearing away of the front edge of the segment is hardly likely to be noticed, since no injury would be looked for until the spark appeared, and then the cutting of the back edge would be much more prominent, because that, being produced by an arc, would have a roughened appearance, while the surface of the front edge would be left smooth by the rubbing off of the melted copper.

Third. The reversal ε may be large enough, not only to reverse the current in the coil under commutation, but even to increase it beyond the value of half the brush current. In this case the extra current would flow through both segment surfaces, but owing to the fact that this current would be increasing while the receding segment was reducing its contact area, that segment would get hottest, and as soon as it reached the melting point an arc would be drawn and destructive sparking would ensue.

The problem that the designer of the modern machine has before him is to design a machine that will run from no load to 25 per cent. above full load without sparking, and without movement of the brushes.

In the case of machines intended for lighting, the condition of no shifting of the brushes is not generally required, but most of our modern lighting machines are made to fill that requirement.

The current to be reversed therefore varies from the exciting current of the machine up to 25 per cent. above its full load current. The inductance E and the CR drop in the coil also vary in this proportion, and for perfect commutation through all these varying loads it would be necessary for the reversal E also to vary in the same proportion. As a matter of fact, the reversal E does not vary in anything like the same proportion, and may even decrease with increase of load, on account of distortion of the flux coming from the field by the armature ampere-turns.

Perfect commutation for any particular position of the brushes can therefore only take place at one value of the load. At heavier loads than this critical one the current is not completely reversed before the segment leaves the brush and at lighter loads it is more than reversed. This problem may be stated a little more precisely in the following manner:—

Assume that the brushes are set as far back as is consistent with sparkless running at the maximum load at which the machine is required to run sparklessly. This means that the reversal E is just equal to the coil impedance E at that point. Now let the load be removed gradually. The impedance E of the coil under commutation is reduced, while the reversal E remains practically constant. The tendency is therefore for the current to be more than reversed, and this tendency increases as the load is reduced, until finally, when the load has been removed entirely, there is no current to reverse, and the reversal E simply tends to produce a current in the coil under commutation. The production of this current is now opposed by the inductance and resistance of the coil, and by the resistance of the brush contact surfaces, the contact surfaces of the two segments being in series as regards this current. If the impedance of the coil is low as compared with this contact resistance, the reversal E would be small compared with the CR drop across the contact surfaces at

full load current. Therefore the current produced by the reversal E would be small as compared with the full load current.

We may also note here, that, whereas the variation of the contact resistances aids the reversal of the current, as soon as this current becomes greater than that which flows through the armature, the excess current must pass across the contact areas of both the segments under the brush. The resistances of these two surfaces are then placed in series as regards this current, and the lowest possible resistance that these could have, would be reached when the brush covers an equal surface on each segment, making the contact resistance in the path of this current equal to twice the resistance of the contact surface of either segment at that time. The resistance of this path then starts at infinity, decreases to this minimum and goes back to infinity again.

Now examine more closely the order of events in commutation at no load. The resistance of the coil circuit first starts at infinity and rapidly decreases, while the reversal E starts at a minimum and more slowly increases. As soon as a current commences to flow, inductance E enters the problem. If there were no contact resistance, the current would reach its normal full load value at about the middle of the commutation period. This of course assumes that the reversal E is of such a magnitude as to reverse the current at full load without the aid of the varying contact resistances. In fact the reversal E does a very small part of the reversing at full load when the inductance is small compared with the contact resistances. The current at the middle of the commutation period would therefore be much smaller than the normal full load current, even if there were no contact resistance to limit it. Now introducing this contact resistance, which starts at infinity and decreases to a minimum, which may be several times greater than the impedance of the coil, the current must be reduced at least in the proportion of the impedance to this minimum resistance. During the rest of that period the resistance is increasing till at the end it has reached infinity again. The current, already very small, is rapidly cut down till it is too small to produce a visible spark at the break, and the commutator has not been heated up enough at any point to produce arcing.

The same principles hold in the case of machines whose brushes must be shifted, the range of sparkless commutation only being less.

There have been some machines, however, which would not run sparklessly for any position of the brushes. This is readily explained on the hypothesis of too high an impedance, for in that case the variation of the current during commutation will be mainly governed by the impedance and reversal E, instead of by the variation of the contact resistances, so that even if complete reversal is exactly attained, the current density at other parts of the commutation period does not remain constant, with the result that the total energy of commutation is increased. A large part of this energy is concentrated at the beginning and end of the commutation period, thus producing heating at the edges of the segments, with its corresponding melting of the copper and arcing.

These considerations indicate two ways by which sparkless commutation may be assured. First by increasing the brush contact resistance, and second by decreasing the impedance of the coil under commutation.

The limitation of the second of these conditions is merely one of economical design, lowering of the inductance below a certain point increasing the cost of the machine.

The limitation of the first condition is that of rise of temperature of the commutator. It has been shown that for perfect commutation the current density is constant and uniform throughout the whole period of commutation. Its value is found by dividing the total brush current by the contact area of the segments under a brush. This varies inversely with the brush contact area, and the energy developed therefore varies in the same proportion. The amount of commutator metal to be heated, as well as the radiating surface, also varies inversely with the current density, so that the rise of temperature probably varies nearly as the square of the current density, provided the commutation be practically perfect.

The increasing use of the carbon brush in place of the copper brush is thus explained by the fact that the contact resistance of carbon on copper per square inch is much greater than that of copper on copper. Increased resistance is obtained with the copper brush by reducing its contact area, but this also reduces the metal to be heated in the commutator, as well as its radiating surface, so that the same amount of commutating energy will result in a much greater rise of temperature.

By taking these facts into consideration, however, and properly proportioning the contact areas and inductance, commutating machines may be designed to run as cool with copper brushes as with carbon wherever this may be desirable.

The reasoning so far has been based on the assumption of but one coil being commutated at a time. This assumption will only be true when the brush thickness is equal to, or less than the width of one segment, plus twice the thickness of the insulation between segments. In practice, brushes are often made to cover a segment and a half, sometimes two segments or even more than this without deleterious sparking. This means that the current in two or more coils is being commutated at the same time.

At first sight this appears to be an advantage, since it enables us to get the same current density with less length of commutator, but the time of commutation is increased, so that while the rate of development of energy is not changed, the total amount of energy developed will vary with the time of commutation, and in addition to this, the amount of metal to be heated and the radiating surface are both decreased, so that in this respect the change is rather a disadvantage than an advantage. Another important advantage is gained, however, in that the increase in the length of the commutation period decreases the reactance of the coil by decreasing its frequency of commutation, so that the ratio of impedance to contact resistance is decreased, thus tending towards more perfect commutation. This advantage is again limited by the fact that the mutual inductance of two coils commutating at the same time increases the reactance of both.

To sum up, the deleterious effects of sparking are due to excessive local heating of the commutator contact surface, causing the copper to melt, and an arc to be drawn, the segments being thus disintegrated.

The causes of deleterious sparking are, either too great a departure from perfect commutation, or too high a current density.

Perfect commutation can only be practically secured by making the impedance of the coil negligible as compared with the contact resistance.

A comparison of the sparking constants of a large number of machines was made before this theory of commutation was evolved.

It has been found to explain many cases of sparking, which had before been unexplained.

It has been found difficult to determine definite safe working constants, on account of the small number of tests that have been made to determine accurately the inductance of the coil under commutation and the effect on each other of two or more coils commutating at the same time.

Discussion.

The Chairman (Mr. Steinmetz):—We have listened to a very interesting paper, and I believe Mr. Reid deserves our thanks very fully for the masterly manner in which he has dealt with this very difficult problem; the most difficult problem, I believe, in the design of direct current constant potential machinery, which electricians have had to meet in the development of the last ten or fifteen years. The discussion is now in order and I call on Mr. Dunn to open it.

Mr. Gano S. Dunn:—I agree with the Chairman as regards the importance of this paper. It was in reference to this feature of dynamo design that Lord Kelvin observed that if as much time had been put upon direct, as has been put upon alternating current apparatus, the direct current would have been as far ahead to-day. In the comments I shall make on Mr. Reid's paper, I only desire to bring out further information so that the subject may be advanced at the end of our discussion.

Mr. Reid states: "The amount of current which will flow from "the brush direct to segment 2 depends on the difference of po- "tential between the brush and segment 2, and on the resistance "of the contact area of segment 2." Later he states that the resistance of the brush is negligible. I think that he is in error,—First, that the resistance of the contact area of the brush is what controls the distribution of current from one segment to the other, and second, that the resistance of the brush is negligible. My work has been to show that the latter is a large and controlling factor in the problem and affects commutation more than does the contact resistance of the brush with the commutator. In proof of this, I will cite the fact that a carbon brush which will stop the sparking on a 25 H. P. motor wound for 110 volts, will not stop the sparking for the same motor when wound for 500 volts. But a graphite brush or carbon brush of very much higher resistance will stop it. In the same connection, where a copper brush will not stop sparking on a 110-volt dynamo, a copper gauze brush will—I believe because of the higher resistance of the gauze and not because of the diminished contact area resulting in a higher contact resistance. I believe that the resistance of the brushes is as much a function of the design of dynamos as the resistance of the armature winding, and that the resistance of the brushes should increase for a machine of given size and output with the square of the voltage for which it is wound. I have been able to prove this law partially. It is impossible to get carbon of all grades of resistance, but graphite may be obtained of any resistance above a certain point to 200 ohms to the inch of length, and I have had made, brushes of varying resistance and found that the low resistance brushes will commutate for low voltages and the higher resistance brushes will commutate for higher voltages, and so on, and while I have not been able to prove the law as one of squares, yet it seems to go up in about that pro-

portion. I would also call attention in this connection to the Wirt brushes which are effective in stopping sparking. They depend on the higher resistance of the leaves of the brush near the outside, to compel the reversal of the coil when the segment is near the brush tips. Now if it was contact resistance, the contact resistance of the external leaves would not differ sufficiently from that of the internal leaves to account for the reversal, and Mr. Wirt finds that by changing the specific resistance of the external leaves of his brush he completely alters the commutating conditions.

The drop of potential in the brush itself is negligible as compared with the circuit voltage, but is not negligible as compared with the reactance of the coil under commutation.

Further on Mr. Reid states: "The D. P. in the coil 3–2 depends on "three factors, the CR drop in the coil, the counter-E. M. F. of self-in-"duction due to change in the value of the current and the E. M. F.

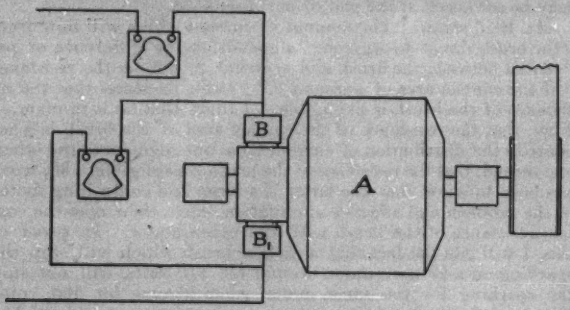

FIG. 1.

"due to cutting the lines of force of the field." And "the CR "drop varies with the current flowing in the coil." And later he also states that the CR drop is an appreciable part of the reactance. With slotted armatures, with which I have had mostly to deal, the CR drop may be neglected, for it forms but about ten per cent. of the total reactance. This brings up the question of how we can divide the reactance into its factors of inductive and ohmic terms, and for that purpose I devised a method some five years ago which I published in a lecture before the New York Electrical Society and which I found to work experimentally very well. It has served my purposes well until recent date when I have computed the inductances of slots instead of determining them empirically. This method of determining the reaction of an armature I will show on the board. Let A (Fig. 1) be an armature of which we wish to measure the reactance. Fix it in bearings away from the influence of any field and be prepared to

drive it with a pulley at its normal speed. Then take its normal full load current from some external source, and pass it through the armature. Now attach a voltmeter from B to B' and note the drop in the voltmeter. This drop will represent the ohmic drop of the conductors in the armature, plus the drop due to the contact resistance. Now spin the armature and note the increase of the drop across it. There will be an increase, because as the current enters the armature, it divides down both sides equally and goes through coils on each side of the brush, which have considerable self-induction, and as the armature revolves each coil has to be reversed which its self-induction opposes. Therefore the current passing through the armature being opposed, the voltmeter will rise. Now subtract from the voltage when the armature is running, the voltage when it is at rest, make allowance for the contact resistance, which may be determined, and for resistance of the brush, and you have directly in volts the reactance of the

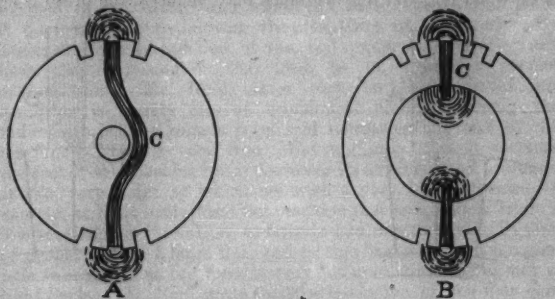

FIG. 2.

armature, and you have it in the way that you most desire to know it. This method measures the reactance at the coil's own high frequency and not at some lower one.

To design dynamos from this empirical method, it is only necessary to take an armature whose reactance you have measured, as a standard of comparison. Measure the length and the depth and the width of its slot, which indicate the permeance and make the dimensions of slots of the new armature in proper ratio to the old. If you want an armature with half reactance make the slot twice as wide, or half as long, or take out some of the turns or use half the frequency. With these empirical methods I have arrived at very accurate and good results. Recently this inductance has been computed, taking into consideration all the factors, and it is remarkable how closely it agrees with the results measured as above. It comes out a little higher, and this I believe is due, as Mr. Steinmetz suggested at the General Meet-

ing at Greenacre, to the fact that the frequency of reversal in the armature is so rapid that the self induction conditions are altered. The frequency in the coil of a direct current armature varies from about 500 to 1500 a second, which is much higher than ordinary frequencies. Now either by computation or by this measurement you can figure out, when you are designing a machine, just how many volts reactance you will have, and can proportion the resistance and area of your brushes accordingly. I have done this a great many times and the results have been what were predicted.

Further on Mr. Reid says: "This arc constitutes the injurious or vicious spark." I would note in this connection that there is a certain condition of sparking which rapidly develops the vicious spark, and I think it is due to the fact that the throwing of this volume of current coming down the brush (B Fig. 3) over into the toe, greatly reduces the resistance of the toe on account of the property of carbon of reducing its resistance when hot, and this resistance once reduced, the brush is de-

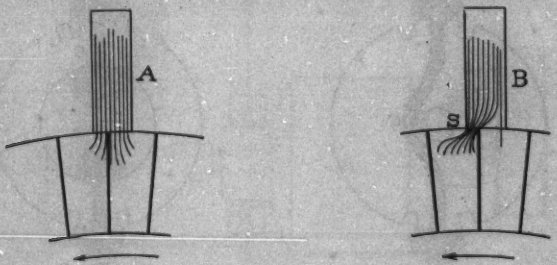

FIG. 3.

prived of its ability to reverse the coil in a still greater measure than before.

I have found considerable difference in the inductance between rings and drums. Why, I have not yet been able to prove, but I presume it is because a ring exposes considerably more area than a drum, and has in addition internal surfaces. If, in Fig. 2, B is a ring armature, and C is the coil, the path of the lines is across the slot, and also up through the air. But there are also paths as shown inside the ring; whereas in a drum armature as A, where the coil is wound straight across, the path can be only from one-half of the peripheral surface to the other.

With regard to terms, Mr. Steinmetz in some of his earlier works on this problem has used the terms "natural commutation" and "forced commutation." By natural commutation he meant such commutation as I have shown, where the brushes did the reversing, and by forced commutation he meant commutation which is done magnetically by the pole tip. I think those terms

are not as appropriate as they should be, and propose the terms "resistance commutation" for the one in which the brush does the work, and "magnetic commutation" for the one in which the pole does the work.

Towards the end of the paper, Mr. Reid states: "These considerations indicate two ways by which sparkless commutation may be assured; first, by increasing the brush contact resistance, and second, by decreasing the impedance of the coil under commutation." If we could increase the brush contact resistance indefinitely we should have a solution of all our troubles. It would only be necessary to build very large commutators, and put much clay or foreign matter into graphite to get it of very high resistance to commutate a 20,000-volt dynamo if you please. But when a brush gets up to such an exceedingly high resistance, the resistance is comparable to the resistance of the hot air at the edge of the brush where the spark occurs. At s, Fig. 3, the resistance of the hot air may be lower than the resistance of the brush, and when you have reached this point it does not pay to increase the resistance of the brush. By decreasing the impedance of the coil under commutation we have the only solution that leads us to hope for perfect commutation. Mr. Reid states that the limitation of this condition is merely one of economical design lowering the inductance below a certain point, and increasing the cost of the machine. That is very true. But not only does it increase the cost of the machine but it decreases its efficiency and decreases at the very point at which we wish a very high efficiency—namely, at light loads; and the machine that is sparkless from a low reactance in its coil, has to have in addition to having its slots of proper design, a large flux, and a large flux while not antagonistic to economy at full load, is very antagonistic to efficiency at light loads. Mr. Reid states that the limitation of the first condition is that of the rise of temperature of the commutator. Commutators in the future will be designed with a certain number of watts per square inch of radiating surface, the same as armatures and field magnets have been designed in the past.

There is an important point, however, that ought to be brought up in this connection. A great many engineers specify a current density in carbon brushes of 30 amperes per square inch. This rule is good as far as the conducting capacity of the brush is concerned; but from a scientific point of view is of no use whatever as affecting commutation. Fig. 3 shows a commutator, and its brush A under conditions of no self-induction, and B with self-induction present. If you think to design for 30 amperes per square inch density, and have a high reactance in the armature coil, what is going to happen? What Mr. Reid calls the "centre of commutation" will move from the middle of the brush over into the toe towards s, and the higher reactance the further into that toe the centre of commutation will move, resulting in having

almost all of your current going down through a small region near the toe, and practically none going through the rest. You think you have 30 amperes per square inch when you may have 200. It is easy to have a lesser actual density than this in a brush of 60 amperes per square inch apparent density by due attention to the inductance, and it is at this latter point specifications should aim, and not at the density for simple conduction. The conduction density is not one to go by, although it is very greatly used and insisted upon. The way to figure the watts per square inch a commutator will have to emit, is to take the reactive volts as measured in the method I have suggested, or as computed—and multiply by the current, and then after adding frictions and ohmic losses put these watts into the surface of the commutator. This is definite, and does not depend upon the cross section of the brush. I will state that the reactive volts in a 25-horse-power 230-volt armature are about two volts, and the ohmic drop in the same armature about five volts.

With regard to the number of sections that a brush should cover, I disagree with Mr. Reid about the effects of covering more than one segment. I have made the experiment, and find that between a brush covering say two segments—and the same brush when you have filed away the edge so that it covers only one segment, the inductive volts differ for 100 per cent. increase of surface only by about 15 per cent. This leads to a point which is not generally known, of the effect on its sparking of the number of segments in an armature. It is thought that to increase the number of segments greatly diminishes the sparking. This is true only as far as relates to the volts per bar. In a 500-volt machine if you get much over 20 or 25 volts per bar between the brushes you will have ring fire and flashing. That kind of sparking is affected by the number of segments. But if you have an armature with 40 segments, and it sparks from inductive causes you will not help it by giving it 80. The reason is that the sparking is a function of the conformation of the slots and armature generally, and is not affected by the number of subdivisions. This comes out in the point about the number of segments the brush covers. It does seem reasonable that if a brush covers two segments of a commutator instead of one, that the time allowed for reversal and the number of lines that will be cut by the coil under the pole would be twice as much, and therefore that the reversal ought to take place much earlier. But that is no more true than the fact that if you short-circuit a hundred cells of gravity battery you will get no more current than if you short-circuit but one. Why is it that the reactive volts measured as I have described, does not vary appreciably when you double or halve the contact area of the brush? I think it is for the reason that the contact area of the brush is not a principal factor, but that the reactance of the armature driving the volume of current over into the toe, determines how much of the brush shall be

used, and therefore it is immaterial whether we have the whole or a part of the brush bearing on the commutator. The criterion that I have established for armatures, is the number of volts that the reactance figures out or measures for a given circuit voltage. On 230-volt machines with ordinary carbon brushes, commutation will take place sufficiently well for heavy duty with a reactive voltage of two volts. If the machine is to be used for intermittent work, and has to have its brushes in the middle, this voltage may be increased to five volts. For 500-volt machines where you can use graphite brushes and have them of as high resistance as you please, the voltage may be increased to double these values. The design of the dynamo ought to be decided for reactive voltage of the coils, as it is decided for ohmic resistance of the armature, for electro-motive force and for other features.

One more point, and that is Mr. Reid speaks of perfect commutation as being obtained by the resistance method. I have pointed out the limitations of resistance commutation. I think that if we ever design very high voltage direct current dynamos we shall do it by means of magnetic commutation. The objection to magnetic commutation at present is this: The fringe at a pole shoe is practically constant, or worse it grows smaller as the load grows larger. Your commutation electro-motive force therefore is fixed, while the electro-motive force of self-induction in your coil varies with the current the coil is carrying. It is zero at no load and high at full load. What you have to do is to set the brush for average conditions and have it hold the commutation back at light loads and help it at heavy loads. If we have a means of magnetic commutation, *e. g.*, a proportioning of the fringe so it varies in strength directly as the load, why can't we depend on magnetic commutation for all loads and for very high voltages? Such for instance would be a supplementary magnet with a coil around it in series with the current going through the motor. As this current increased, the magnet would strengthen and give more magnetic fringe for magnetic commutation directly in proportion to the need of the coil. I have been working on a method of this kind to be applicable to high voltage machines, and while in the course of every-day life we are very busy and do not have a chance to develop all our ideas I hope some day to see high voltage generators designed on this principle.

THE CHAIRMAN:—(Mr. Steinmetz). Gentlemen, we can congratulate ourselves on having had Mr. Reid's masterly paper supplemented by the very interesting and valuable discussion of Mr. Dunn.

There is one point in Mr. Reid's paper towards the end, in the discussion of the desirable width of brushes, which may be slightly modified by taking into view another quantity—the friction of the brush on the commutator, which heats the commutator just

as much as the $c^2 r$ does. This friction loss varies naturally with the width of the brush. So taking this into view his conclusion should be slightly modified.

I may answer Mr. Dunn regarding his desire that commutators should be designed by considering the watts per square inch, that for about two years past all the commutators of the company with which I am connected are designed this way, by calculating the energy lost of the commutator by the friction of the brush and the $c^2 r$ loss of the contact resistance, and figuring thence the necessary area of the commutator to dissipate this amount of energy. As pointed out by Mr. Dunn, the use of very low impedance is inefficient, due to the very high flux, giving high light load loss. In the commutator you have a similar feature. The $c^2 r$ loss at the brush contact varies with the load, but the friction loss is constant, and thus a light load loss. The lower you take the current density of the brush, the lower also is the light load efficiency of the brush. It is hardly appreciated by most people what an enormous amount of energy is wasted at the commutator of the low voltage machines. In a 50-volt machine this loss is very frequently five per cent. and more, of the output, and obviously the most economical design is very near that, where the variable loss is equal to the constant loss, or the friction loss, at the load at which the machine is desired to operate mostly. This means that the best current density at the brush contact, is not 30 amperes and not 40 amperes, but depends on the peripheral speed of the commutator. For high-speed commutators, a higher current density is usually preferable, in low speed commutators a lower current density. All this has to be taken into account now in designing commutators of direct current machines.

I do not agree with Mr. Dunn that the resistance of the brush proper is the main factor, but I agree rather with Mr. Reid that it is the contact resistance. It is undoubtedly true that special brushes can be made with high internal resistance, but with ordinary carbon brushes the internal resistance of the brush is negligible, compared with the contact resistance.

The experience of Mr. Dunn and this apparent law of voltage is very easily explained thus: If we rewind a machine, say for twice the voltage, we get twice as many turns on the armature, or per commutator segment, of half the cross-section, that is four times the resistance, and four times the reactance. That means we have to have four times the resistance in the brush to get the same relative proportion of reactance, etc., as commutation constants. If a machine sparks, for instance, as a 550-volt machine more than a 110-volt machine, it is due to the fact that, while the contact resistance is the same numerically, it is only one-twenty-fifth relatively to the reactance in the 550-volt machine as in the 110 volt-machine, and that I believe explains the feature.

I agree that resistance commutation is a very desirable name, and better than natural commutation. But I do not agree with

the word magnetic commutation, for the reason that the word magnetic commutation has a definite meaning already. It means the commutation of the magnetic circuit. There are quite a number of apparatus in commercial use now-a-days where commutation of the magnetic flux takes place, as magneto-potential regulators and such apparatus, where primary coils and secondary coils are stationary with regard to each other, and merely the direction of the magnetic flux is changed by moving a part of the magnetic circuit. Even the ordinary inductor alternator is really a kind of magneto commutation machine. Thus I think to avoid confusion it is better to find another term expressing this phenomon.

MR. DUNN:—May I comment on your remark about the reactance? The reactance of a dynamo at double voltage would be four times the reactance of the other if the current were the same; but the current is only one half; therefore the reactive volts vary as a direct function of the circuit voltage and not as the square, and therefore the resistance of the brush requiring to go up as the square, does not follow the same law as the increase of the reactive volts.

THE CHAIRMAN:—Yes, it does; because the resistance volts decrease with the current. If the reactance volts increase only proportionately to the voltage the resistance volts which enter the same circuit decrease with the current, that is, inverse proportional to the voltage. You either have to compare resistances and reactances, or resistance volts and reactance volts; in either case, you get proportionality to the square of the voltage.

This leads to another feature which I forgot in discussing the reactance volts. This reactance E. M. F. is really not a constant voltage. In your experiment the measured voltage really does not give you directly the reactance, because the reactance E. M. F. is not a steady voltage during commutation, nor is it an alternating voltage, as the term "frequency of commutation" implies, but it is a very complex exponential function. Since the resistance varies with some kind of linear or even more complex law, the problem of commutation leads to a differential execution, which we cannot integrate any more; that is, I do not know whether it can be integrated; I tried once and did not succeed.

MR. DUNN:—I do not think after this that anybody will attempt to integrate that equation.

THE CHAIRMAN:—Is there any more discussion on this paper?

MR. REID:—I may be able to start this discussion again by speaking of some of the questions brought up by Mr. Dunn's remarks. To begin with the first thing, he speaks of the brush resistance itself being of more importance than the brush contact resistance, and he says that he has measured this brush resistance in special cases and found that the brush resistance, itself being increased, has stopped sparking. The question that occurred to me was, whether the brush contact resistance was not increased at

the same time. I have not tried it and do not know. I have only used one form of carbon brush, and I have never used the Wirt brush. In the case of the difference between the copper brush and the gauze brush, it struck me that the contact resistance of the gauze brush would be higher than the strip copper brush.

Then, in regard to the cR drop of the coil under commutation being negligible as compared with the reactance, I have found that in a good many cases, but not in all, and I think that Mr. Dunn's finding it so can be explained by some other points in his discussion. He says that he gets two volts reactance in a 35 horse-power motor. In no motor that I have dealt with have I got over half a volt reactance. So I imagine that he must get rid of his sparking by some other means than I have used, as two volts would chew my commutator up in very short order. In all that Mr. Dunn said, it impressed me that he was still clinging to the idea that the cause of injury in sparking was this jumping of the spark across the gap between the receding segment and the brush; I am not sure that I was right in that, but that was the impression I got from his remarks. Now the main point that I intended to bring out in this paper was the fact that the injury was done before the segment left the brush; that the spark was a mere indication of injury already done; that is, when the segment leaves the brush, the copper has already been melted; the current goes through this melted film of copper and volatilizes the copper which would have been taken away from the segment anyway.

In regard to the test for reactance, I agree with Mr. Steinmetz in that. We have a variation of contact resistance all the time, and various other quantities that would make it very difficult to say just what was measured by that test. I never heard of the test before, and would not be sure that it was not accurate, but at the first sight it appears to me to take in too many variables for us to be certain what we have when we get through.

Then, in the latter part of Mr. Dunn's discussion, he seemed to me to assume imperfect commutation. He speaks of the limits of resistance commutation. I do not see that he mentioned any such limit, and I do not see how there could be any as far as commutation was concerned. Of course, the resistance commutation, what I have called perfect commutation, might be very expensive. That is one limit. But otherwise, the more perfect the commutation, the better the machine.

In regard to magnetic commutation which he recommends, and which he says might be done by means of an extra pole. So it might. People have been trying to do it for a long time, but I haven't found that anybody has succeeded very well as yet. We have had various shapes of poles and various other devices for performing what he calls magnetic commutation. But I have yet to see any machine regularly manufactured, with any simple

form of magnetic commutation. There are one or two, or one at any rate, the Ryan dynamo, which is very complicated. There is no other that I know of that has been regularly on the market, but if anybody can get it, I think it is a very good method.

Then there is another objection to that also, that I mentioned in my paper, and I think really it is the reason that these magnetic commutation machines have not been successful. When speaking in the paper of the machines that spark at any position of the brushes, I attribute that to the fact that the commutation was entirely regulated by the inductance or impedance of the coil and the reversal E. M. F., and therefore the density in the brush contact might vary even if the current were reversed, and if the brush density does vary, the energy of commutation increases necessarily, and if, therefore, you commutate by means of a pole opposing inductance, you will get a variation of current which is not the best for low energy at the contact surface, and the energy may be concentrated at the point near the edge of the brush, where it would do most harm.

MR. DUNN:—With regard to the first point that Mr. Reid makes as to the resistance of the brush, stating that he did not know but that my cases had been accompanied by a diminution of the brush contact and therefore a change of the brush contact resistance, I would say that I have had a machine that sparks with a copper gauze brush of 30 mesh and I have put upon the same machine a brass gauze brush of the same dimensions and mesh and it stopped the sparking. Now I think that leaves very little chance for change of contact resistance.

MR. REID—May I interrupt you a moment? What I meant was not change in the area, but change in the resistance due to change in the substance. I did not mean to say that you had changed the contact area of the brush, but simply that the change in the substance of the brush itself with the same contact area would change the contact resistance.

MR. DUNN:—As to that, I do not know. But Prof. Crocker had some experiments a year or so ago upon the contact resistance between moving metal surfaces of copper and various brushes bearing upon it, including carbon and various metals, and as I remember it, the contact resistance did not vary very much between the different metals. We can certainly get the information from that source.

Now with regard to the aspersions upon this two volt reactance. I have designed machines that have sparked, but in this case you are attacking one that does not. The armature wound for 500 volts, has even between four and five volts reactive drop, and I have run it at 60 per cent. overload with practically no sparking, and at 20 per cent. overload with absolutely no sparking.

With regard to the damage being done by the sparks at the toe of the brush, I thoroughly agree with Mr. Reid. He has

brought out a very valuable point. Commutators can be cut very badly and injured so that the machine is useless, without a spark appearing at the brush until after the harm has been done.

With regard to the contact resistance, I have before me some results of a test I made this afternoon, thinking to compare the contact resistance of graphite with the contact resistance of carbon which I knew about. With carbon, the contact resistance is not constant, but rises very rapidly at first with the least motion of the armature. The armature, if stationary, might have a drop across it of 4.2 volts when the slightest motion by the hand would bring that up to 4.4 volts, but after that first rise has taken place suddenly, then it seems to go on evenly. Now this is for carbon, and gives two-tenths of a volt due to change of contact resistance with speed, out of a reactive drop of 2 volts; which shows if we do make an error in estimating the change of contact resistance, it will not affect our result very largely; but the same cannot be said of the graphite brushes. The graphite brushes behave in the most extraordinary manner. The volts may go up a whole volt when you start to turn the armature the smallest amount. I suppose that is due to the nature of the graphite and one reason why telephones are so good.

With regard to magnetic commutation, I was only indulging a little. I know that the magnetic commutation has not been successful so far, but that does not mean that it cannot be, and I simply hope to see it successful.

THE CHAIRMAN:—Gentlemen, it seems to me that the question whether the contact resistance or the internal resistance of the brush is larger, is a more relative one, and depends on the kind of brushes used. With ordinary carbon brushes, I know that the internal resistance of the brush is entirely negligible compared with the contact resistances. But with these Wirt brushes with insulation between the leaves, the internal resistance of the brush may be far larger than the contact resistance, although I have never tested them. Now, the effect on the commutation must be undoubtedly very nearly the same whether the resistance is in the contact or internally. In regard to the question whether the contact resistance depends on the material or not, I may state that it does depend. The contact resistance of the ordinary commutator brush carbons is many times larger than the contact resistance of copper brushes. Curiously enough, the contact resistance of graphite is very similar, but the magnitude of the resistance drops given by Mr. Dunn is entirely different from anything I ever found at the current densities commonly used. The contact resistance voltage of continuous current machines is found something like one volt or more, but not tenths of volts. It varies slightly with the speed, not very much. This resistance applies to the carbon brush on a commutator running at some thousand feet a minute, not standing still. Standing still, the resistance is very much less.

MR. DUNN:—I would like to bring out one further point that may be of interest. It has a bearing on the fact that the resistance of the brush and not of the contact has to do with the reversal of the coil. I do not mean that the contact resistance has no effect, but the volumetric resistance does have a large effect. I have taken sparking which would occur with a brush of the kind shown at Fig. 4, and have stopped it by using a brush of about the same spread on the commutator, but inclined as at B. That would make, you see, the reversing current volume, which is thrown over into the toe of the brush, discriminate between the toe and the heel of the brush, and help the reversal by having a longer path of consequently higher resistance at the toe. If it is true, then the form of brush which bears on the commutator in the opposite direction, as in C, Fig. 4, would be less valuable for stopping sparking than the other, but I have never made any measurements or experiments on this.

DR. A. E. KENNELLY:—One of the principal points in this very interesting paper is one that seems to me to have occupied

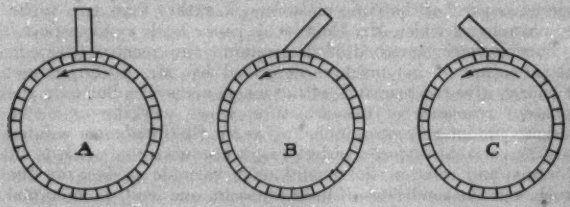

FIG. 4.

less attention than it deserves. The theory of sparking considered in the paper is more than the theory that has generally been advanced, by reason of the melting process. The theory considered here is the theory that has generally been advanced plus the effect of melting the copper and discharging that melted copper across the gap. In other words, Mr. Reid has taken the ground that the damage is done before the brush leaves; where, as according to the ordinary theory, the damage is not done until the brush has left the commutator bar. It seems to me that this can scarcely be differentiated from the ordinary theory, because whenever the conditions are present which will produce a powerful discharge at the moment of leaving the bar, it seems to me that you have the conditions which will produce a very powerful current and produce this very melting he speaks about. In other words, you cannot have a powerful current density at the edge of the commutator segment, such as would melt it, without having the conditions favorable to producing the very discharge that the spark ordinarily has been considered to be. The cause of

sparking, we all agree upon as being a difference of potential between the edge of the brush and the edge of the commutator segment, and that difference of potential is ordinarily due to self-induction of the coil and the commutation. The electro-motive force of the self-induction is that which produces the discharge. That electro-motive force can be neutralized in two ways; first, by the resistance method, by opposing to it a drop of pressure produced in the toe of the brush producing an electro-motive force available for opposing the electro-motive force of self-induction. The second way is by introducing into the moving coil under commutation, an E. M. F. induced by magnetic flux.

In some cases that is done by forcing the brushes forward. In other cases it is done by employing a separate pole, as in the Ryan and Sayers machines. When you get a sufficient difference of potential at the point of discharge to obtain a powerful spark, surely you are likely to have a sufficient current density at the edge of the commutator bar to produce this high temperature and melting and volatilizing. So do not these two effects of sparking and melting merge together, and shouldn't they be considered as parts of the same phenomenon, rather than two separate phenomena which Mr. Reid in his paper leads us to suspect.

This interesting method of determining the reactive drop in the armature of the machine described by Mr. Dunn, cannot of course, give the reactance of the whole armature, but only the apparent reactance of the armature, when working as a continuous current generator, including as Mr. Steinmetz has pointed out, the variable surface contact resistance under conditions of vibration and rotation, the conditions of variable surface on the brush, and the conditions of inductance in one coil, as modified by the local surroundings, since if you put the same armature into the pole pieces, the apparent inductance of the coil is liable to be varied. But the method shows how carefully we should distinguish between what is commonly called the resistance of the armature including the brushes, when stationary, and when running.

MR. REID:—In regard to Dr. Kennelly's contention that the melting would not occur unless there was sufficient energy at the edge of the brush to draw sparks, there was one kind of commutation mentioned, where there would be no sparking with destruction of the commutator, and on the other hand there was another where there would be sparking without any injury to the commutator. The first case was where the entering segment had a higher current per square inch than the receding one, where the copper was melted in the front part of the segment and carried over onto the back. That is where there is no spark. The commutator gradually wears away and the spark appears after a while. Then the other case was where the current is not entirely reversed by the time the segment leaves the brush, but the segment leaves the brush with a small difference of potential,

and the spark jumps across and does no harm, because the main part of its energy is dissipated in the air between the segment and the brush. Unless there is melted copper there through which to draw an arc, as you do in an arc lamp, no harm will be done. That was the principle I brought out, and I think still that that is a correct one.

MR. DUNN:—In vindication of my method, the experiments and the computations also will show that it does not include a number of uncertain quantities, or quantities of importance in comparison with the result. Now, in this armature our reactive drop (which is the difference between the drop when the armature is standing still, and when it is moving) is about two volts. With carbon brushes in which the variation of contact resistance is small the measured value of the reactance comes out about three-quarters of the computed value after all allowances have been made for contact resistance, brush resistance and variation of contact resistance with speed. I think this remarkably close in view of the very high frequency which introduces uncertain elements and is a proof of the method.

MR. KENNELLY:—In regard to what Mr. Reid has said, no doubt it is true when you get sufficient current density at the edge of the commutator bar you will melt it, and no doubt it is true that when you enter a segment with too much current density, you will melt the segment. But when the brush leaves a bar, if there be any considerable difference of potential between the two, there will be a spark. The question is, whether so soon as there is much spark discharge, there will not also be sufficient heat to melt the edge of the bar.

MR. REID:—In the case of the Ruhmkorff coil, or any other coil of that character, you can get sparks all day, and it will not hurt your points. You can get large sparks, and the points may be mere needle points, and they will stay there all day. You can get the same thing in commutation. You can get sparks going from the segment to the brush, and provided there is no melted copper or volatilized copper to form an arc, you can get sparks all day that will not hurt your commutator. We often have what I call the blue spark, and we have it on railway motors all the time, —I do not mean on all of them, but we have it on railway motors that will run right straight along, year in and year out, with the spark,—and the commutator will be just as hard and glossy as you like. The spark is no indication of injury. The only injury that is done is when the copper is melted before the brush leaves the segment. We may have any amount of sparking, not vicious sparking, however, so long as you please, (I might say, if it is a blue spark), and it will not injure the commutator.

THE CHAIRMAN:—The best instance of such a harmless spark is the open coil arc light machine. That machine requires for stable commutation a spark of considerable length, and the spark runs on all night and day without hurting the commutator, be-

cause the current is limited—not sufficient to volatilize the copper. That brings up another feature, namely, that Mr. Reid's paper and the whole discussion have dealt with one kind of commutation only, which, however, is not the only kind, because a very large class of machines, the arc light machines, commutate in an entirely different manner. With them it is neither resistance commutation nor magnetic commutation. or, as it is perhaps preferable to call it, magnetic field commutation; but a different phenomenon, which would take too long to discuss here, but which might very properly form the basis of a separate paper. It takes place in open coil arc machines, alternating current rectifiers and self-exciting synchronous motors or alternators. Thus, you see, the commutation discussed in this paper is not the only kind of commutation which exists.

Dr. Wm. E. Geyer:—I should like to ask the gentlemen who have discussed this matter, whether in their treatment they have considered another electromotive force which I think has not been mentioned. I have reference to thermo-electric electromotive force. That we all know is very small, and we ordinarily despise it. But in this case where the junction of two similar metals is at the melting point of copper, and the other ends are relatively cold, I imagine we might get quantities worth considering.

The Chairman:—I may answer that question in the negative, in so far as I cannot see how you can get the effect of thermo-electromotive force, since having two couples in series, whatever electromotive force you get on the positive brush must be opposed by an opposite electromotive force at the negative brush, so the result must be zero, I should think.

Dr. Geyer:—I have reference to the action at one of the brushes, not to the machine as a whole, but to the actions around a single brush.

The Chairman:—I do not know of any tests made in this respect.

If there is no further discussion on this subject we will proceed to the second part of the programme, an exhibition of "Wireless Telegraphy." But I would suggest that in view of the very interesting paper, a vote of thanks to Mr. Reid would be proper.

Mr. Dunn:—May I have the pleasure of moving a vote of thanks from the Institute to Mr. Reid for his very able paper.

The Chairman:—The motion is carried. I thank Mr. Reid here in the name of the Institute, for his very interesting and valuable paper which I am sure will be of importance and value in our Transactions even after years.

The second part of the programme is now in order, an exhibition of "Wireless Telegraphy." I will call upon Dr. Kennelly to take the Chair.

WIRELESS TELEGRAPHY.

December 15, 1897.

MR. W. J. CLARKE:—Mr. Chairman and gentlemen: Having been requested this evening to give you an exhibition of the Marconi apparatus, I am pleased to be able to say that I am in a position to do so. I think perhaps it might be well to give you a short explanation of the apparatus which we use. In the first place, we have here on the front of the base, a Marconi coherer consisting of a small glass tube, fitted with silver plugs connected to platinum wires at the end. These plugs are very close together, about the centre of the tube, the intervening space being filled in with nickel filings. I have found that it is entirely unnecessary to either exhaust or seal the tube. I also find that we can use almost any kind of metal for the filings. When the cohesion is examined under the microscope, I find that what we have to provide for is the proper size of the filings, and not the proper kind of metal. This coherer is placed in series with this relay which is of about 1200 ohms resistance, and made extremely sensitive, more so than the ordinary Morse relay. In series with it, also, are two cells of small dry battery placed in the base. These are arranged so that we can use either one cell or two, the object of this being that when the cells are new, we can use only one in order to prevent corrosion of the filings where they cohere. As the cells grow older we simply throw our *a* switch, and use two cells. This sounder is a 20-ohm instrument. It is placed in multiple with this cohering apparatus consisting of a 20-ohm vibrator placed in the base. The local battery consists of three cells of dry battery arranged as with the main battery, so that we can either use one, two or three of the cells. This Morse key is simply used in order that we may see that the apparatus is in proper condition. Pressing this key short-circuits the coherer. Our transmitter consists of an eight-inch induction coil. A much smaller one, though, is all that is necessary for a short distance. This coil has its secondary terminals connected with two brass balls, each an inch and a half in diameter. These balls are brought into close proximity, in fact in most cases touching two large brass balls, four inches in diameter. The large balls are securely cemented in the ends of a rubber tube, and the distance between them on the inside of the tube is about one-thirty-second of an inch. The space between the balls in the tube is filled with the purest quality of vaseline oil, and the moment that we close the circuit through the primary of the coil the electric waves generated strike the coherer, the filings cohere, and the resistance is sufficiently reduced to operate the relay. Sometimes we have trouble with this particular instrument, not on account of the system being imperfect, but on account of the fact that it is the first piece of portable apparatus

that I know of built in this country, and of course you understand that the first piece of apparatus is liable to imperfection. I think now that everything is in proper shape, and I will proceed to the other room and close the circuit of the primary of induction coil, and I think you will see the receiver respond, and after doing this we will close the doors and work the receiver through the glass doors.

[Apparatus shown in operation.]

THE CHAIRMAN:—[Dr. Kennelly]. Gentlemen, you have witnessed an interesting exhibition, and I am sure that many must be desirous of asking Mr. Clarke some questions upon the difficulties he has had to encounter in making this instrument, and the various matters he has found necessary to take into account. I am sure that if he is as ready to answer as he has been ready to describe the apparatus that he will respond.

MR. GANO S. DUNN:—I should like to ask whether the circuit remains closed while the shower of sparks is passing, and also, if Mr. Clarke would describe the action of the coherer.

MR. CLARKE:—I would like to say that with proper adjustment, the circuit remains closed as long as the primary circuit of the induction coil is closed, and as long as the vibrator of the induction coil is in action. Unfortunately the adjustment which we have on our decohering apparatus in this instrument is not sufficiently under control, so that I cannot get the fine adjustment necessary for transmitting intelligible Morse signals, but this is simply a question of proper adjustment. Now with regard to the coherer, as I said before, it simply consists of two conductors separated by a very short interval, this space being filled with metallic filings. The filings are of such a size and the distance apart of the conductors is such, that while the filings are lying loose, the resistance through the tube is very high indeed. But the moment that the filings cohere, the resistance is very much reduced, so much so that the current in series with the relay is able to pass to a sufficient extent to operate the relay. I may say that I have been so very busily engaged in getting a smaller and less expensive set of apparatus ready for the market, that I have not had an opportunity to experiment very largely with the question of the distance, but I expect during the next week to be able to accomplish something in that direction.

MR. DUNN:—I have done a good deal of telegraphing and am familiar with the frequency requisite to get all the signals in. For instance, when the operator is sending very rapidly, his "e" dot, by the time it reaches the other end may be only a very small fraction of a second. I noticed the frequency of your coil was readily observable, I could almost count it by beats, and I wanted to inquire how long one discharge of the coil would cause the filings to cohere, and hold the circuit closed.

MR. CLARKE:—The coherer, when in proper shape, in which this hardly is, is so very sensitive that it is not necessary to have

a vibrator on the coil at all. It is simply necessary to have a Morse key. The coherer responds the moment you close the circuit, only in this case, of course, it simply coheres and decoheres instantly, and the circuit of the sounder is closed and opened.

MR. DUNN:—If when you close your key on the induction coil that causes the filings to cohere, and then decohere immediately, your sounder here would make its down click, and be followed by its up click when the key in the other room has not risen.

MR. CLARKE:—Yes.

MR. DUNN:—Then you would have to use some different system from the ordinary Morse for sending.

MR. CLARKE:—No, because when we use the vibrator on the coil, and everything is in proper adjustment, the filings cohere as long as our coil is working, and decohere the moment we stop it by opening our key.

MR. DUNN:—The vibrator frequency is about 800 a minute.

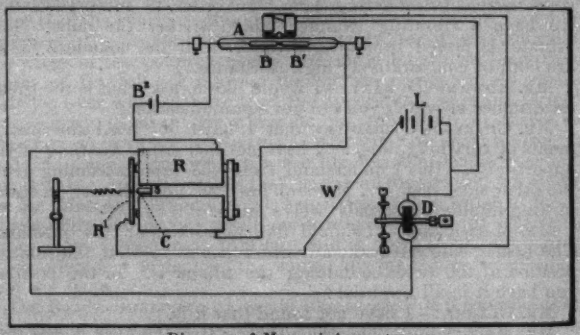

Diagram of Marconi Apparatus.

MR. CLARKE:—Well, I may say that the coil we are using is not the coil that we use for quick signaling. We use a Tesla coil for that purpose, a very high-frequency coil.

THE CHAIRMAN:—I might suggest for the benefit of some who may not be familiar with the subject, that if you sketch the outline of the connection on the board it may help.

MR. CLARKE:—I will do that, I might say that at some future time I would be very glad to show you the stereopticon diagrams on the sheet, of the different classes of this apparatus we are making up. It is a little difficult to explain it on the blackboard, but I will do the best that I can. Here we have the coherer A somewhat enlarged. These B B' are the silver plugs. The filings are between the ends of those plugs. The main battery B' is connected to one end of the coherer. The other ter-

minal of the battery is connected to one terminal of the 1200-ohm relay R. The other terminal of the relay is connected to the coherer. Now when the apparatus is in its normal condition, the relay is so adjusted and the resistance of the filings is such, that the current from the battery will not pass to a sufficient extent to operate the armature of the relay, but when the waves from the transmitter strike the filings and they cohere to each other, and also to the silver plugs, as examination under the microscope shows that they do, the resistance is so reduced as to allow sufficient current to pass from this battery to operate the relay. The moment the relay operates, it pulls up its armature, making the contact C. The moment this contact is made, the current from the local battery L traverses the wire W to the armature of the relay R', from the armature across the contact to the screw S, back to the sounder D and back again to the battery. Now once the filings have responded to the waves and cohere, they will remain cohering unless we have some means of decohering them. In order to accomplish this, we have a vibrating hammer which strikes the tube. This vibrator is placed in multiple circuit with the sounder. They are both of comparatively high resistance.

MR. EDWARD DURANT:—I would like to ask what is the greatest distance at which you can get communication?

MR. CLARKE:—I may say that I have not tried the instruments at very long range. I have not had either the time or the opportunity. But I understand from the reports coming from the other side, that Mr. Marconi has had no difficulty in transmitting intelligible signals twelve miles.

MR. MACGREGOR:—I should like to ask one or two questions. The first is,—does it make any difference as to what the relative position of the tubes containing the filings is. Is the position you have it in all essential?

MR. CLARKE:—I have not found that it is.

MR. MACGREGOR—The second thing I want to ask is, whether there is any fixed relation between these two pieces of apparatus. In other words, would any other induction coil produce the same effect as this one, or are these two instruments related so as to form a pair? If intelligence transmitted from one piece of apparatus could be read by any one of a hundred machines, this method of telegraphy would have its disadvantages.

MR. CLARKE:—In the first place, I have not found using the short ranges over which I have tried the apparatus, that it makes any difference in what position either the receiver or transmitter is placed. In regard to their being any tune, as we may call it, between the transmitter and receiver, I may say that Marconi claims that it is absolutely necessary to have the transmitter and the receiver in what we might call synchronism. In order to accomplish that, he takes two strips of copper, each about half an inch in width, and attaches them to the end of his tube, one

on each end. These strips of copper he claims have been shortened or lengthened in accordance with the frequency of our transmitting apparatus. In order to ascertain what is the proper length, he takes a piece of glass and pastes upon it a strip of tin foil about half an inch in width, and two or three feet in length. He divides this strip in the centre with a very sharp knife. He sets his transmitter in a dark room and places this testing apparatus in front of it, at a few yards distant. He operates his transmitter, and when he does so, the same as in the experiments of Hertz, he notices small sparks passing across between the divided tin foil. He moves his tester further from the transmitter until the sparks entirely disappear. Then he cuts off, say half an inch, from each end of his tin foil and immediately the sparks reappear. He goes further, until the sparks disappear again, and he keeps on cutting down each end of his tin foil, until he finds that he is working in the other direction, and that if he cuts it any more, he simply has to go back closer to the coil in order that the sparks at this point will reappear. Then he finds he has got the proper length. Accordingly, he cuts what he calls the wings of the coherer nearly the same length as these two pieces of tin foil. I may say that in the comparatively small distance over which I have tried the apparatus, I have not found it necessary to have any wings on the tube at all, or that it is necessary to have the apparatus in any kind of synchronism, I find that some recent writers in the London *Electrician* bear me out in this. I see it stated that in one of the exhibitions given by Mr. Marconi, or some of his associates, that in order to show how readily the waves would go through a piece of iron, the coherer was placed in an iron box, and in order to place it there, it was necessary to remove the wings, but the coherer responded just the same.

Dr. Sam'l Sheldon:—I would like to ask if it is essential that you should have silver for the two electrodes.

Mr. Clarke:—The only object, as far as I can see, is simply to keep the points of contact clean.

Dr. Sheldon:—Then the object of a vacuum would be to prevent the silver from oxidizing.

Mr. Clarke:—Yes, and I may say in this connection too, that experiments have been tried with putting the filings in hydrogen gas, but it was found that they speedily became too bright and clean, so much so that they cohered all the time. If the filings are examined under a microscope and the waves are acting upon them, it will be noticed that the moment they decohere you will see little bright spots where the particles of metal have been touching each other. Those bright spots rapidly disappear.

Mr. C. T. Child:—I would like to ask if that decoherer is in the nature of an electro-magnetic vibrator.

Mr. Clarke:—Yes.

MR. CHILD:—How do you shield the coherer from the waves sent out from that instrument?

MR. CLARKE:—We do not find that it affects them in the least.

MR. CHILD:—I should think that those waves would affect it.

MR. CLARKE:—Well, Mr. Marconi claims that it does. I have not found any effect at all. Perhaps it is because I have guarded against that by cutting down the sparks at the contact with resistance coils, and also placing a resistance across the terminals of all the magnets.

A MEMBER:—I fancy that the resistance must be very low with those metal filings there, so low that the variation must be very small as we find at once in telephone experiments where we use metal filings. May I ask what the resistance is of that coherer?

MR. CLARKE:—I may say that although I have the facilities, I have not had the time to make a thorough test in that direction and I can only guess at what the resistance really is. I expect very shortly to devote very considerable time in making a thorough test.

THE CHAIRMAN:—It is very high, isn't it?

MR. CLARKE:—I hardly think so, because you will see we have a resistance in the relay of 1200 ohms, and one cell of dry battery is all that we require to operate it. In fact if we use silver filings it is difficult to get them to decohere enough to interrupt the flow of current. I should have stated that silver is the only metal I have found that is too sensitive.

MR. WINTRINGHAM:—How so?

MR. CLARKE:—If we use silver filings we find it almost impossible to adjust the apparatus so that the circuit will remain open and then close when the waves strike it. Silver filings are so very clean and bright, that they form a very low resistance across the plugs in the tube, much lower than nickel or any other metal that I have tried. I have not tried gold or any metal of that kind. I do not know how they would act.

THE CHAIRMAN:—If there are no further questions, I feel sure that you will endorse my recommendation that a vote of thanks be extended to Mr. Clarke for his kindness in exhibiting the apparatus, and in so patiently answering all our questions prompted by a very natural curiosity. I need hardly put that to vote. I think I am justified in extending that vote of thanks.

MR. ALBON MAN:—Will the gentleman answer one question? The origin of waves seems to be provided for between the large balls in the rubber tubes. Why are not other waves generated between the small balls and the large ones, or are they generated, and do they have the same effect as the ones in the tube? I understand that sparks pass between the terminals of the small balls and the large ones.

MR. CLARKE:—Yes.

MR. MAN:—Are they not a source of electrical waves?

MR. CLARKE:—In regard to that I can hardly say; I have not experimented far enough. Mr. Marconi claims that it is necessary not only to use two balls four inches in diameter in the tube, but also use the other balls of the same size. Now I find that over the short distance that I have worked the apparatus, it is not necessary even to have the small balls at all. All that is necessary is to connect the terminals of the coil to the large balls, and I have used a coil of only one inch spark capacity. I feel quite positive that a coil of that size is all that is necessary for transmitting this distance.

MR. MAN:—I would like to know also if the diameter of the large ball and its mass, is a necessity to the transmission of the waves, or the production of the waves. Has the mass of the balls anything to do with the force of the waves?

MR. CLARKE:—I can only say in regard to that, that I have followed Mr. Marconi's experiments very closely. I have only so far constructed a transmitter with the four inch solid brass balls. Marconi claims that it is absolutely necessary to have solid balls for long distance transmission, and that with hollow balls, the distance over which we transmit will be less than half. My own impression is, that hollow brass spheres filled with lead, or other inexpensive metal, would be just as good, and we are going to experiment with that shortly, and also with the smaller spheres, on account of the larger spheres being very expensive and very heavy.

MR. MAN:—Hertz found his electrical waves produced as readily from small balls, or even any kind of a spark as from larger masses. It was for that reason that I asked the question.

MR. CLARKE:—Knowing the results of the experiments of Hertz, I am of the opinion myself that the size and mass of the ball does not make the difference that is claimed for it, and for that reason we are going to experiment in order to determine that accurately.

MR. HAMBLET—I move a vote of thanks to Mr. Clarke for the very interesting exhibition that he has given us this evening.

[The motion was carried, and the meeting adjourned.]

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